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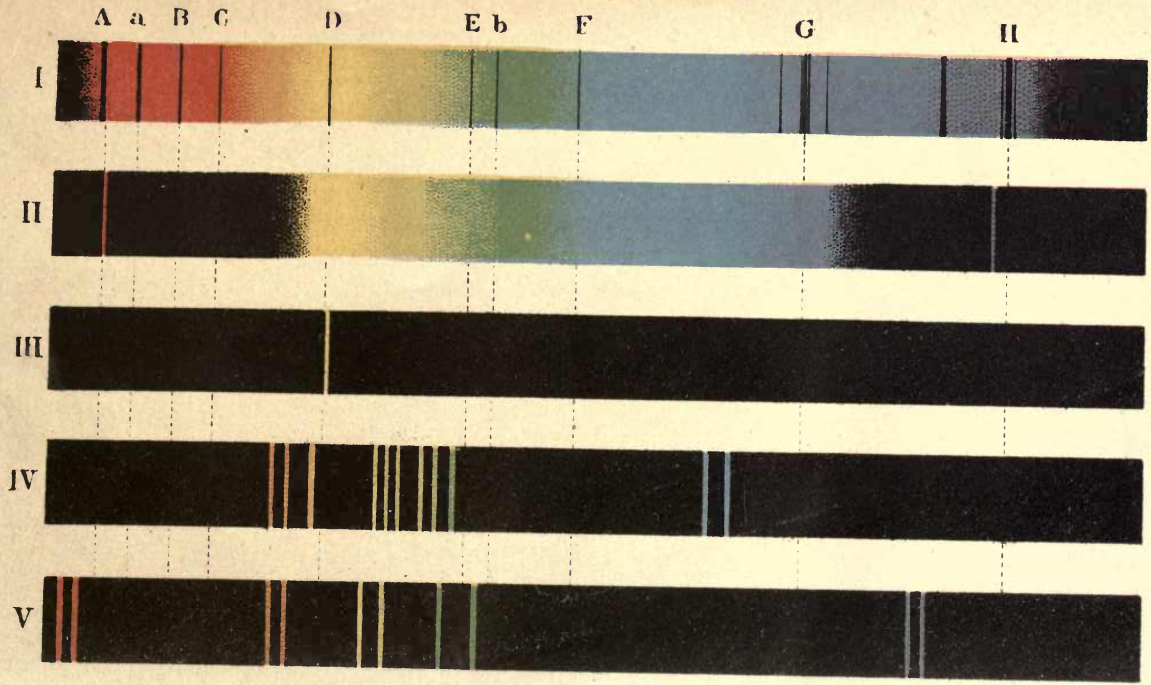
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The Cambridge Course of Physics.

NATURAL PHILOSOPHY,

FOR

HIGH SCHOOLS AND ACADEMIES.

BY

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PREFACE.

THE authors were led to prepare this series mainly that they might provide themselves with text-books containing an elementary view of the present state of the Physical Sciences. The general plan and method of the Course were worked out by Mr. Gillet, and thoroughly tested in the class-room by oral teaching, before there was any thought of publishing the books.

The authors felt, from experience, that the elementary text-books on Physics now in use are, as a class, deficient in two important particulars. First, they are sadly behind the times; and, secondly, they fail to give any systematic development of leading principles. A great revolution has taken place during the last twenty-five years in the departments of Chemistry, Electricity, and Heat. In Chemistry this revolution has been so complete that the present theories of the science are currently known as "Modern Chemistry." The hypothesis of electric fluids has been swept away, and Heat has been shown to be a mode of molecular motion. It is but recently that Helmholtz has given the correct explanation of the formation of the vowel sounds, of resultants, and of dissonance; and that Tyndall and others have investigated the subject of sounding and sensitive flames. In Optics, too, the cause of long and short sightedness, and the way in which the eye adjusts itself for near and distant objects, have been correctly understood only within a few years. In Astronomy, also, the analysis of solar and stellar light by means of the spectroscope has led to discoveries of the highest interest; while recent investigation has thrown much light upon the nature of the photosphere and spots of the sun.

As the principles of physical science are all established by facts of observation, the method has been adopted in this Course of first establishing the fact by experiment, when this is possible, and of then drawing out the principle. The *summaries* always come at the end of a topic, not at the beginning.

The authors believe that the simplest experiments, and those which require the simplest apparatus, are usually the best, and they have therefore sought to give such experiments in all cases.

From their experience in teaching, the authors strongly recommend that each lesson be explained and illustrated with the class before being given out to be studied.

In preparing the present volume, the material for the SOUND has been drawn almost wholly from Tyndall's "Lectures." This valuable work is now brought within the reach of all teachers by the neat reprint of the Appletons (New York, 1867).

Much of the material for the LIGHT has been taken from Ganot (Traité Élémentaire de Physique, 12[e] édit., Paris, 1866), Herschel (Familiar Lectures on Scientific Subjects, London, 1867), and Potter (Physical Optics, London, 1856).

In treating of HEAT, we have drawn mainly from Tyndall's "Lectures" and papers, and from Stewart (Heat, Clarendon Press Series, London, 1867).

In ELECTRICITY we have been greatly indebted to Faraday's "Researches," to Noad's "Manual of Electricity, to Dr. Ferguson's "Electricity" in Chambers's Educational Course (Edinburgh, 1866), and to Professor Cooke's "First Principles of Chemical Philosophy" (Cambridge, 1868).

The chapter on the PHYSICS OF THE ATMOSPHERE is mainly condensed from Buchan's "Handy Book of Meteorology" (*second edition*, Edinburgh, 1868). The teacher will do well to get this book, and also Professor Loomis's excellent "Treatise on Meteorology" (recently published by the Harpers), to which we have once or twice referred.

CAMBRIDGE, November 15, 1868.

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THE ELEMENTS OF NATURAL PHILOSOPHY.

I.

PRESSURE.

1. *Solids.* — If we take hold of any part of a stone and lift it up, the whole stone comes up. The parts of the stone hold together firmly, so that when one part is moved they all move in a piece. Wood, iron, lead, and many other bodies, are like stone in this respect. Such bodies are called *solids.*

2. *Liquids.* — If a goblet be filled with water and slowly tipped, the water runs out, not all together, but a part at a time. The parts of the water do not hold together so firmly as those of the stone. When the water is poured from the goblet, all its parts do not move in a piece, as those of a solid would do were it tipped from the same goblet. Alcohol, quicksilver, and many other substances, resemble water in this respect. Such substances, whose parts move easily among themselves, are called *liquids.*

3. *Gases.* — If water be poured into a goblet from above, it readily fills. If, however, a goblet be inverted and pressed down upon water, it does not fill with water. The reason it does not fill is, that it is already full of air. When it is inverted and pressed down upon the water, there is no chance for this air to escape; but when the water is poured in from above, the air readily escapes from the mouth of the goblet.

The air in the goblet is quite unlike either a solid or a liquid. Air and other substances like it are called *gases.*

All substances are called *matter.* There are, as we have seen, *three states of matter,* the *solid,* the *liquid,* and the *gaseous.*

4. *Matter is acted upon by Gravity.* — When a stone is held in the hand, it is felt to press downward. There is some force drawing it towards the earth. This *force* is called *gravity.*

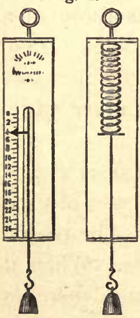
WEIGHT.

5. The downward pressure which gravity causes a body to exert is called its *weight.*

When different bodies, as iron and wood, are taken in the hand, it is easy to feel that some are heavier than others, but it is not so easy to tell exactly how much heavier one is than another.

6. *The Spring Balance.* — But the weight of a body may be made to bend a spring, and, when different bodies are made to bend the same spring, we can readily tell how much heavier one is than another by seeing how much more it bends the spring. If it bends the spring twice as much, it is twice as heavy; and if three times as much, it is thrice as heavy. An instrument for finding the weight of a body by seeing how much it can bend a spring, is called a *spring balance.* One form of this balance is shown in Figure 1. It consists of a steel spring wound into a coil. One end of this coil is fastened to a ring, and the other to a hook. The body to be weighed is fastened to the hook, and the whole raised by the ring. The weight of the body straightens or draws out the spring. A pointer moving over a plate in front, which is divided into equal

Fig. 1.



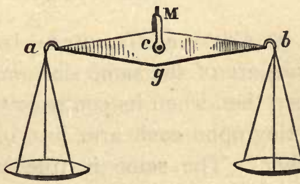
parts, shows how much the spring has been drawn out. A body which will straighten the spring a certain amount is said to weigh a pound; one which will straighten it half as much, half a pound; one fourth as much, a quarter of a pound; twice as much, two pounds; and so on.

7. *The Balance.* — If a straight rod be supported on a pivot, in the centre, so that it can turn freely, as shown in Figure 2, it will remain level or horizontal. If now a pound of lead be hung from each end of this rod, it will still remain horizontal. The two pieces of lead will just balance each other. If a second pound of lead be hung from one end of the rod, it will require a second pound at the other end to balance it. If then we have a number of pieces of lead of different sizes, whose weight is known, we can readily find the weight of any other body by hanging it to one end of the rod, and adding the pieces of lead to the other end till they balance it. If one pound of lead will balance it, its weight is one pound; if a quarter of a pound of lead will balance it, its weight is a quarter of a pound; and so on.

Fig. 2.

An instrument for finding the weight of a body in this way is called a *balance*, and the pieces of lead or iron used in weighing it are called *weights*. A common form of the balance is shown in Figure 3. It consists of a bar turning on a pivot in the centre, and having pans hung from each end for holding the weights and the body to be weighed.

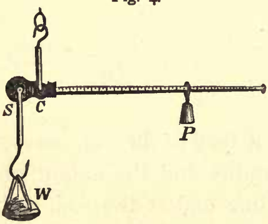
Fig. 3.



8. *The Steelyard.*—If we have a straight rod balanced like the one above, with one arm considerably longer than

the other, and a weight of a quarter of a pound is arranged so that it can slide along the longer arm, it will be found, on hanging a weight of a quarter of a pound to the end of the shorter arm, that the weight on the long arm must be placed just the length of the short arm from the pivot, in order to balance the weight on the short arm. If a half-pound weight be hung to the short arm, the weight on the long arm will have to be placed twice the length of the short arm from the pivot, in order to balance it. If the weight on the short arm is three quarters of a pound, then the weight on the long arm must be placed three times the length of the short arm from the pivot, to balance it; and so on. We can then find the weight of a body by hanging it to the short arm, and seeing how far the weight on the long arm must be placed from the pivot, to balance it.

Fig. 4.



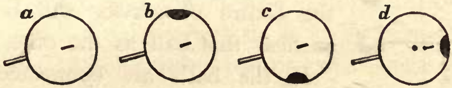
An instrument for finding the weight of a body by this method is called a *steelyard*. A common form of the steelyard is shown in Figure 4.

THE CENTRE OF GRAVITY.

9. *Centre of Gravity.* — In the case of the bar whose arms are of the same size and of equal length, it has been seen that, when its centre is supported, the force of gravity acting upon each arm just balances that acting upon the other. The same is true when one arm of the bar is twice as long as the other, provided the shorter arm is twice as heavy as the longer.

If a circular disc of wood (Figure 5) be pierced at the centre and supported upon a wire, it will remain at rest in whatever way it may be turned. In this case, then, the force of gravity acting upon the part of the disc to the right of the support always exactly balances that acting upon the part to the left of the support. If, however, one part of the disc be loaded with lead or other heavy substance, it will no longer rest equally well in every position. It will now remain at rest only when the loaded part of the disc is

Fig. 5.

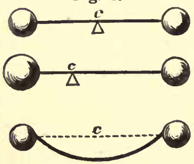


either directly under or over the support. It is found on trial, however, that there is still a point between the loaded side and the centre, upon which the disc will rest in any position. In this case also it is clear that the force of gravity, acting upon the part of the disc to the right of the support, always exactly balances that to the left of the support. Such a point can always be found, whatever may be the size or shape of a body, and of whatever material it may be made. This point is called the *centre of gravity.* The centre of gravity of a body, then, is a point such that the force of gravity acting upon the part of the body on one side of this point always balances the force of gravity acting upon the part on the opposite side, no matter how the body may be placed.

10. *The Centre of Gravity not always in the Body itself.*— If a straight strip of metal or wood be fastened to the sides of a ring so as to pass through its centre, it will be found that the ring will rest in any position when the centre is supported; and that it will not remain at rest in every position on any other point. The centre of gravity, then, of a ring which is exactly alike throughout its whole extent is at the centre of the ring. If one part of the ring is heavier than the other, the centre of gravity will be found to be between the centre and the heavier part.

When two balls of the same weight are connected by a straight rod (Figure 6) the centre of gravity will be found to be at the centre of the rod. If one ball be twice as heavy as the other, the centre of gravity will be in the rod at a point twice as near the heavier ball as the lighter ball. If the heavier ball be three times the weight of the lighter ball, the centre of gravity will be thrice as near this ball as the other.

Fig. 6.



If the balls are connected by a curved rod, the centre of gravity will no longer be in the rod, but in a straight line which joins the balls. Its distance from the balls will be as above.

11. *Equilibrium.* — If the loaded disc in Figure 5 be placed with its loaded part down, it remains at rest. If it be turned a little either way and then let go again, it returns at once to its former position of rest. If now it be carefully poised with the loaded side up, it can be made to rest; but if we turn it the least either way, it does not go back to the position of rest which it has just left, but at once takes a new position of rest with the loaded side down.

The disc *a*, which is of the same material throughout, remains at rest equally well in any position.

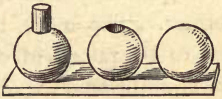
When a body is at rest it is said to be *in equilibrium.* When it is at rest in such a position that on being slightly disturbed it again returns to this position, it is said to be in *stable equilibrium.* When it is at rest in such a position that on being slightly disturbed it seeks a new position of rest, it is said to be in *unstable equilibrium.* When a body remains at rest equally well in any position, it is said to be in *indifferent equilibrium.*

12. *The Centre of Gravity always seeks the Lowest Point.* — We have just seen that when the loaded disc (Figure

5) is in the position *b*, if we disturb it in the least it falls into the position *c;* and that, if it be moved from this position *c*, it will at once return to it. It will be seen that, in this position *c*, its centre of gravity is lower than in any other position. And so in every case it will be found that the centre of gravity of a body seeks the lowest position which it can take.

13. *The Stability of Equilibrium.* — A sphere which is of the same material throughout, is in *indifferent* equilibrium (11) on a level surface, because the centre of gravity can fall no lower than it is. If a portion of the upper part of the sphere be removed by making a hole there (Figure 7), the equilibrium becomes *stable*, because the centre of gravity is brought below the centre of the sphere, and will have to rise if the sphere is moved either way. If the upper part of the sphere be loaded by putting into the hole a cylinder which more than fills it, the equilibrium becomes *unstable*, because the centre of gravity is now brought above the centre of the sphere, and any motion either way tends to lower it.

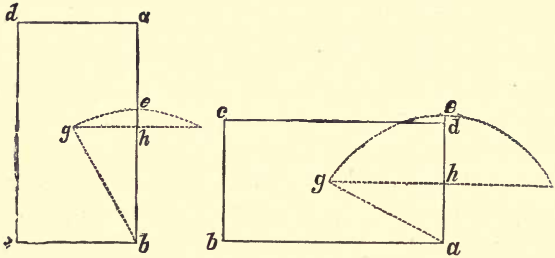
Fig. 7.



When a body is so situated that its centre of gravity is raised by tipping it in any direction, it is in *stable* equilibrium; when any disturbance of the body tends to lower its centre of gravity, it is in *unstable* equilibrium; when on being disturbed its centre of gravity neither rises nor falls, it is in *indifferent* equilibrium.

In Figure 8, *g e* shows the path which the centre of gravity *g* must take when the body is tipped. Until *g* reaches the point *e* the body tends to go back, because in so doing the centre of gravity would fall; but as soon as *g* passes *e* the body tends to go over, because in so doing the centre of gravity would fall. *h e* shows how much the centre of gravity must be raised to overturn the body; and this distance is seen to be greater when the

Fig. 8.

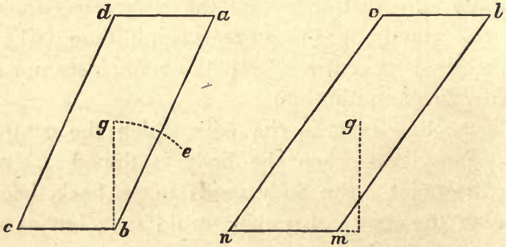


body is resting on the side *a b* than when it is resting on the side *b c*. It will be found that much more force will be required to overturn it in the latter case than in the former. The more, then, the centre of gravity of a body has to be raised in order to overturn it, the more stable its equilibrium.

It will also be seen from Figure 8 that the broader the base of a body compared with its height, the more stable its equilibrium.

If, however, the body is not upright, it may be in unstable equilibrium even when the base is broad. In Figure 9 *g e* is the path which the centre of gravity *g* must

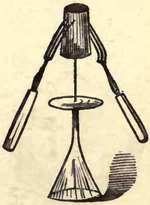
Fig. 9.



take when the body *a b c d* is overturned, and it will be seen that, as soon as *g* is moved at all in the direction *g e*, it begins to fall and the body will go over. In the body *l m n o* the centre of gravity *g* is not supported, and the body will fall over of itself.

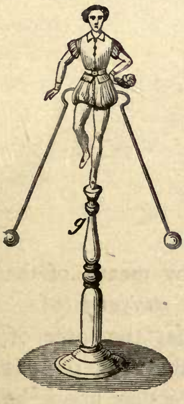
It is evident, then, that a body may lean and yet be in equilibrium, provided the centre of gravity is directly over any point of the base. If this point be well within the base, the equilibrium may be very stable, as in the case of the famous leaning tower at Pisa.

Fig. 10.



On the other hand, a body may be in stable equilibrium even when the base is very narrow. Thus a cork may rest upon the point of a needle, and yet be in stable equilibrium. This may be done by sticking two forks into the cork, as shown in Figure 10. The forks bring the centre of gravity below the point of support, so that the cork cannot be tipped without raising the centre of gravity. In the same way, the image in Figure 11 is balanced on its toe by means of the two heavy balls beneath. So, too, in the "prancing horse" (Figure 12) the centre of gravity is brought below the point of support by the leaden ball at the end of the curved rod.

Fig. 11.

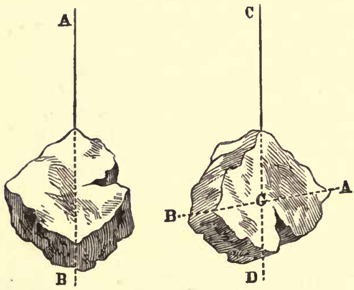


14. *How to find the Centre of Gravity of a Solid.*—When a stone, as in Figure 13, is hung by the cord *A*, the centre of gravity must be directly under the point of support; that is, somewhere in the line *A B*. If the same stone be hung by the cord *C*, its centre of gravity

Fig. 12.

must still be below the point of support, somewhere in the line *C D*. Since the centre of gravity is in both the lines *A B* and *C D*, it must be at the point *G*, where they cross.

Fig. 13.



To find the centre of gravity of a solid, then, suspend it from any point of its surface by means of a cord, and notice the direction which the cord takes. Then suspend it from another point, and again notice the direction of the cord. The point where lines drawn in these directions would cross each other will be the centre of gravity.

SUMMARY.

Matter exists in *three states*. (1 – 3.)
Matter is acted upon by *gravity*. (4.)
Gravity gives bodies *weight*. (5.)

The weight of bodies may be found by means of the *spring balance* (6), the *balance* (7), or the *steelyard* (8).

A point can always be found such that the force of gravity acting upon the part of a body to the right of it is always balanced by the force of gravity acting upon the part to the left of it, no matter in what position the body may be placed. This point is called the *centre of gravity*, and sometimes lies within a body and sometimes without it. (9, 10.)

When a body is at rest it is said to be *in equilibrium*. Its equilibrium may be either *stable*, *unstable*, or *indifferent* (11.)

The centre of gravity always *seeks the lowest position* which it can take. (12.)

The *stability* of the equilibrium of a body depends upon the position of the centre of gravity, and upon how much it must be raised to overturn the body. (13.)

The centre of gravity of a solid may be found by suspending the solid from two different points of its surface by means of a cord. (14.)

PRESSURE OF LIQUIDS.

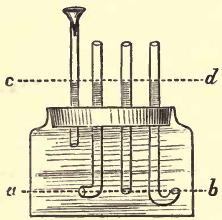
15. *How to find the Weight of a Liquid.* — If a cup be placed in one pan of a balance and weighed, and then filled with water and weighed again, it will be found to weigh more in the second case. This shows that liquids, as well as solids, are acted upon by gravity, which causes them to exert a downward pressure. The weight of the water in the cup is the weight of the cup when full of water *less* the weight of the empty cup. If the cup is filled with quicksilver and weighed again, it will be found to weigh much more than when filled with water. This experiment shows that some liquids are heavier than others.

16. *Liquids when acted upon by Gravity press, not only downward, but also upward and sideways.* — Fix a long tube into the top of a wooden cask, and put a stop-cock into the top, and another into the side of the cask. On filling the cask and the tube with water, and opening the stop-cocks, the water is driven out of both. This shows that the water in the cask, when acted upon by gravity, presses upwards and sideways as well as downward.

The pressure which liquids exert sideways is called *lateral* pressure.

17. *The Upward, Downward, and Lateral Pressures are equal for the same Depth of Liquid.* — In Figure 14 we

Fig. 14



have a glass vessel, into the top of which are inserted three glass tubes of exactly the same size, with their mouths at the same distance from the bottom. One of these tubes opens downward, one upward, and one sideways. On filling the vessel with water, by means of the funnel, the liquid rises to the same height in all three tubes. Now it is the upward pressure which causes it to rise in the tube opening downward, the lateral pressure which causes it to rise in the tube opening sideways, and the downward pressure which causes it to rise in the tube opening upward; and since the tubes are all of the same size, and since the water rises to the same height in each, these pressures are all evidently equal.

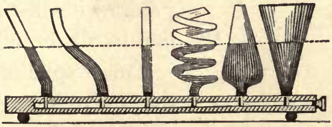
The upward, downward, and lateral pressures are then the same for the same depth of liquid.

18. *The Upward, Downward, and Lateral Pressures of a Liquid increase with the Depth, but are not altered by the Size or Form of the Vessel which holds the Liquid.* — The more water we pour into the vessel, in Figure 14, the higher the water rises in the tubes. The upward, downward, and lateral pressures increase with the depth of the liquid.

If the tube into which the liquid was poured be removed from the vessel, and other tubes of different sizes and shapes, but of the same height, be put in its place and filled with water, the liquid rises to exactly the same height in the tubes; showing that the upward, downward, and lateral pressures of a liquid are not altered by the size or shape of the vessel which holds it.

For this reason, when vessels of different sizes and shapes are connected, as shown in Figure 15, if a liquid be poured into one of them it will rise to the same height in all.

Fig. 15.

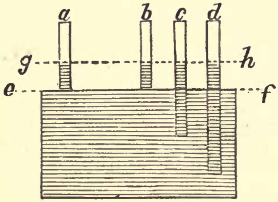


19. *When a closed Vessel is filled with a Liquid, and any additional Pressure is brought to bear on any Particle of this Liquid, every Particle is made to exert the same additional Pressure, upward, downward, and sideways.* — Suppose the four tubes in Figure 14 are all of exactly the same size, and that the vessel is full of water. Pour water into the left-hand tube until it rises to the line *c d*. The water rises in all the tubes to the same height. The water poured into the first tube brings an additional pressure to bear upon the particles of water at its mouth, and it is the additional pressure which the particles at the end of the other tubes are made to exert that causes the water to rise in them. Now the water rises to the same height in all the tubes, and since they are all of the same size there must be the same number of particles at the end of each; therefore, the particles at the end of the three tubes are made to exert the same additional pressure upward, downward, and sideways, as that brought to bear upon the particles at the end of the left-hand tube.

At whatever depth these three tubes open, the water will be made to rise in them all to the line *c d*, showing that all the particles of the liquid are made to exert the same additional pressure upward, downward, and sideways.

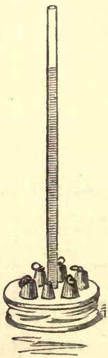
That the particles at different depths are all made to exert the same additional *upward* pressure is shown by the apparatus in Figure 16. The three tubes *b c* and *d* open at different depths, and the vessel is first filled with water, which rises in *c* and *d* to the line *ef*. Pour water into the tube *a* till it rises to the line *gh*, and it will rise to the same line in all the tubes.

Fig. 16.



This explains the action of the *hydrostatic bellows*, represented in Figure 17. It consists of two boards connected by a band of leather, forming a closed vessel, and a tube is inserted in the top or at the side. Weights are placed on this board, and water is poured into the tube. As the water fills the tube, the board rises with the weights upon it. If the surface of the board is 100 times as large as the end of the tube, one pound of water in the tube will balance 100 pounds on the board. As the surface of the board is 100 times as large as the end of the tube, there are 100 times as many particles of water in contact with the board as there are at the end of the tube, and as each particle is made to exert the same pressure, one pound of water in the tube ought to balance 100 pounds on the board.

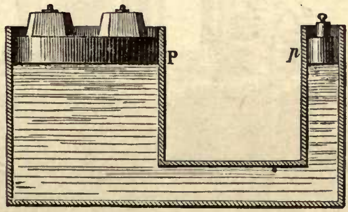
Fig. 17.



The particles of a liquid under pressure act like bent springs pressing equally in all directions. In an open vessel, gravity acting upon the upper layer of particles makes them press upon those of the second layer, which then act like bent springs against all their neighbors, which in turn become as bent springs. In this way the pressure of the upper layer is transmitted equally throughout the whole mass. But gravity pulls down the second layer as well as the first, and their pressure also is transmitted through all the mass below, so that the third layer receives twice the pressure of the second. In the same way the fourth layer receives three times the pressure of the second; and so on. When pressure is exerted upon any particle of a liquid in a closed vessel, it is made to act like a bent spring upon all its neighbors, which in turn act in the same way either upon other particles or upon the sides of the vessel.

20. *The Hydrostatic Press.* — It follows, from what has just been shown, that by means of a liquid a small pressure upon a small surface may be made to exert a great pressure upon a large surface. In Figure 18 we have two cylinders, with a plunger, or piston, in each. Suppose that

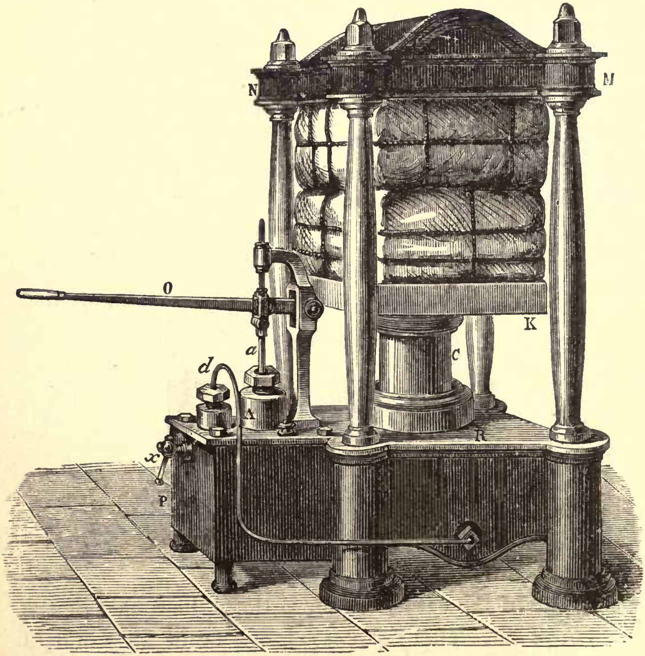
Fig. 18.



the surface of the larger piston is thirty times that of the smaller; if the latter is pressed downward by a weight of one pound, an upward pressure of one pound will be brought to bear upon each portion of the surface of the large piston equal to that of the small piston. The whole upward pressure on the large piston will then be thirty times the downward pressure on the small one. If the surface of the larger piston had been sixty times that of the smaller, one pound on the latter would have balanced sixty on the former; and so on.

Advantage is taken of this fact in the construction of *the hydrostatic press*, shown in Figures 19 and 20. The two cylinders *A* and *B* are connected by the pipe *d*. The piston *a*, in the small cylinder *A*, is worked by the handle *O*, and forces water into the large cylinder *B*,

Fig. 19.

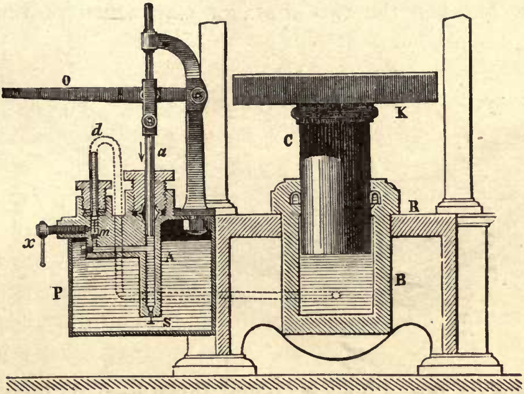


where it presses up the piston *C*. If the end of the piston *C* is 1,000 times as large as that of the piston *a*, a pressure of 2 pounds on *a* would exert a pressure of 2,000 pounds, or one ton, upon *C*. If a man in working the handle *O* forces down the piston *a* with a pressure of 50 pounds, he would bring to bear upon *C* a pressure of 25 tons.

This press is used for pressing cotton, hay, cloth, etc., into bales, for extracting oil from seeds, testing cannon, boilers, etc., and for raising ships out of the water.

21. *Springs and Artesian Wells.* — All natural collections of water illustrate the tendency of a liquid to find

Fig. 20.



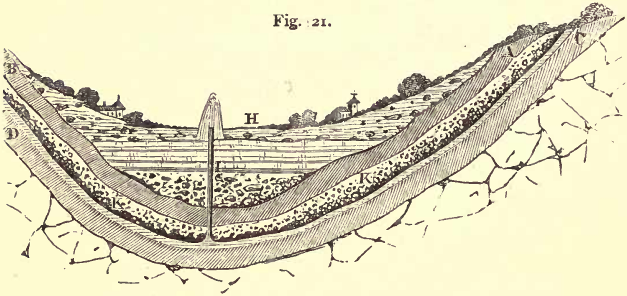
its level. Thus, the Great Lakes of North America may be regarded as a number of vessels connected together, and hence the waters tend to maintain the same level in all. The same is true of the source of a river and the sea, the bed of the river connecting the two like a pipe.

Springs illustrate the same fact. The earth is composed of layers, or *strata*, of two kinds; those through which water can pass, as sand and gravel, and those through which it cannot pass, as clay. The rain which falls on high ground sinks through the soil until it reaches a layer of this latter kind, and along this it runs until it finds some opening through which it flows as a spring.

It is the same with *Artesian Wells.* These wells derive their name from the Province of Artois in France, the first part of Europe where they became common. It would seem, however, that wells of the same kind were dug in China and Egypt many centuries earlier.

In Figure 21, suppose *A B* and *C D* to be two strata of clay, and *K K* to be a stratum of sand or gravel between them. The rain falling on the hills on either side will filter down through this sand or gravel, and collect in the hollow between the two strata of clay which prevent its

Fig. 21.



escape. If now a hole be bored down to *KK*, the water, striving to regain its level, will rise to the surface at *H*, or spout out to a considerable height above it.

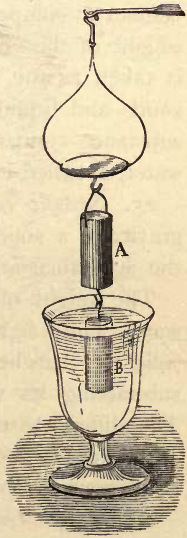
The Artesian well at Grenelle, in France, has a depth of 548 metres, or about 1800 feet, and the water flows out at the rate of 656 gallons a minute, or nearly a million gallons a day. One in this country, at St. Louis, is 2,199 feet deep, and affords 75 gallons a minute.

22. *A Body is buoyed up when placed in a Liquid.* — If a stone be fastened to one pan of a hydrostatic balance and weighed under water, it will seem to be lighter than when weighed in the ordinary manner in the air.

We have already seen that at the same depth in a liquid the upward and downward pressures just balance, but that these pressures increase with the depth. The bottom of the stone in the above experiment being deeper in the water than the top, the upward pressure of the water against the bottom of the stone is greater than the downward pressure of the same liquid upon the top of the stone. The stone is accordingly lifted up a little when plunged under water, and being thus buoyed up, seems to be lighter than in the air.

23. *A Body is buoyed up in Water by a Force just equal to the Weight of the Water which it displaces.* — In Figure 22, *A* is a cup into which the cylinder *B* exactly fits. This cup then will hold just as much water as *B* displaces when under water. Hang this cup and cylinder to the hydrostatic balance, and balance it with weights. Immerse the cylinder *B* in a vessel of water, and we find that it is more than balanced by the weights. Now, by means of a dropping tube fill the cup *A* with water from the vessel. When the cup is full, the cup and cylinder are seen to be again just balanced by the weights. This shows that a body when immersed in water is buoyed up by a force just equal to the weight of the water which it displaces.

Fig. 22.



It is evident from this that, if a solid weighs exactly as much as the water it displaces when fully immersed, it will neither rise nor sink in the water. If it weighs more than the water it displaces, it will sink ; if less, it will rise. When a body floats upon the water, it displaces exactly its own weight of water. It is well known that a lump of iron will sink, but the same lump of iron may be hammered out into a vessel which will displace its own weight of water without being wholly immersed.

In this way, ships may be made of iron which will float upon water as well as ships made of wood.

SPECIFIC GRAVITY.

24. *Substances vary in Density.* — When the same bulks of different solids and liquids are weighed, their weights are found to be very different. A substance which weighs more, bulk for bulk, than another substance is said to be more *dense*, or to have a greater *density*. It is often desirable to know the relative weights of the same bulks of bodies which vary in density. In such cases, it is convenient to compare the weight of each substance with the weight of the same bulk of some given substance. Water is taken as the substance with which the weights of other solids and liquids are compared. The weight of a given substance compared with the weight of the same bulk of water, is called its *specific gravity*.

25. *Specific Gravity of Solids.* — To find the specific gravity of a solid or liquid, we must know the weight of the substance and that of the same bulk of water.

The weight of the solid can be found in the ordinary way. The weight of a bulk of water equal to that of the solid can then be found by weighing the solid in water, and subtracting its weight in water from its weight in air. The difference of these weights is, as we have seen (23), just equal to the weight of the water it displaces, and this is, of course, a bulk of water just equal to its own bulk.

26. *Specific Gravity of Liquids.* — The specific gravity of liquids is most conveniently found by means of an instrument, shown in Figure 23, called a *hydrometer*. It consists of a hollow glass cylinder, with a stem and scale-pan above, and a small bulb filled with mercury below, by which it is made to float upright in a liquid. The instrument is placed in water, and weights are added until it sinks to a point marked upon the stem. The weight of the hydrometer, together with the weights in the pan, is equal to the weight of the water displaced (23). If now the instrument be

placed in another liquid whose density is not the same as that of water, as alcohol, and made to sink by weights to the mark on the stem, the weight of an equal bulk of that liquid can be found. The specific gravity of the liquid will, of course, be the weight of the liquid divided by the weight of the water.

Fig. 23.

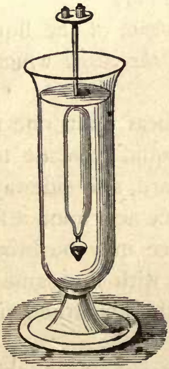
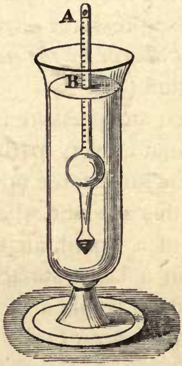


Fig. 24.



A more common form of hydrometer is shown in Figure 24. It consists of a glass tube and bulb loaded with mercury at the bottom. This, when put into a liquid in which it will float, always displaces just its own weight (23). It is first put into pure water, and the point to which it sinks is marked upon the stem. If it be now put into a liquid of less density, it will sink deeper; if into one of greater density, it will not sink so deep. By means of the scale on the stem, the specific gravity of the liquid into which it is put is indicated.*

* See Appendix, I.

SUMMARY.

Liquids have weight as well as solids (15). When acted upon by gravity they *press upward, downward, and sideways* (16).

The upward, downward, and lateral pressures are always *equal for the same depth* of the liquid (17).

These pressures *increase with the depth* of the liquid, but are *not altered by the size or shape of the vessel* which holds the liquid (18).

When any pressure is brought to bear upon one particle of a liquid, every particle of the liquid is made to press with the same force upward, downward, and sideways (19).

On this account, when a small force acts upon a few particles of a liquid, an enormous force may be brought to bear on a large surface in contact with the same liquid. Advantage is taken of this fact in the construction of the *hydrostatic press* (20).

Springs and Artesian wells illustrate the tendency of water to *seek a level* in connected vessels (21).

A body is buoyed up in water by a force equal to the *weight of the water which it displaces* (22, 23).

The *specific gravity* of a solid or liquid is the weight of the solid or liquid compared with the weight of the same bulk of water (24).

To find the specific gravity of a solid or a liquid, we must know the weight of the substance and that of the same bulk of water.

The weight of a bulk of water equal to that of the solid can be found by weighing the solid in air and in water (25).

The specific gravity of a liquid may be found by means of a *hydrometer* (26).

PROBLEMS.

WEIGHT OF LIQUIDS.

1. A glass flask when full of water weighs 180 grammes.* The flask itself weighs 84 grammes. How many grammes of water does the flask hold?

2. The same flask when full of mercury weighs 1382 grammes. How many grammes of mercury does it hold?

3. The same flask full of alcohol weighs 160 grammes. How many grammes of alcohol does it hold?

4. The same flask full of sulphuric acid weighs 220 grammes. How many grammes of sulphuric acid does it hold?

THE PRESSURE WHICH LIQUIDS EXERT BY REASON OF THEIR WEIGHT.

☞ In these problems it is assumed that in liquids the pressure increases at exactly the same rate as the depth.

5. When water is one centimetre deep in a vessel it exerts a pressure of one gramme on every square centimetre of surface at the bottom of the vessel. What would be the pressure exerted upon every square centimetre of surface at the bottom, if the water in the vessel were 3 centimetres deep?

6. What would be the pressure upon 9 square decimetres of surface at the bottom, if the liquid were 6 centimetres deep?

7. What upon 13 square decimetres at the bottom, if the liquid were 17 centimetres deep?

8. A closed vessel is 3 decimetres deep, and has a tube projecting from the top to the height of one metre. The bottom of the vessel has a surface of 50 square decimetres,

* See French Weights and Measures, p. 114.

and the vessel is filled with water to the top of the tube. What is the whole pressure upon the bottom of the vessel?

9. What would be the pressure upon a square centimetre of surface on the side of the above vessel, the centre of the surface being 3 centimetres from the bottom?

10. What would be the pressure upon a square centimetre of surface at the top of the vessel?

11. What would be the pressure upon the whole upper surface of the vessel, supposing it to contain 50 square decimetres?

12. A cubical vessel, every side of which is a square metre, is filled with water. What would be the pressure upon its bottom?

13. What would be the pressure upon each of its sides?*

14. Suppose the top of the above vessel were closed and a tube one metre in length were inserted into it, on filling the tube to the top what would be the pressure exerted upon the top of the vessel?

15. What would be the pressure upon the bottom of the vessel when the tube is full of water?

16. What would be the pressure upon the sides of the vessel in the last case?

THE HYDROSTATIC PRESS.

17. The end of the small piston in a hydrostatic press has a surface of 10 square centimetres; and the end of the large piston a surface of a square decimetre. A pressure of 10 kilogrammes upon the small piston would bring what pressure to bear upon the large piston?

* To find the pressure upon any surface at the sides of a vessel, take the *average* depth of the surface, that is, the distance from the top of the water to the middle of that surface.

18. If the small piston be the same as above, and the end of the large piston contain a square metre of surface, 5 kilogrammes upon the small piston will cause what pressure to be brought to bear upon the end of the large piston?

19. A pressure of 75 kilogrammes on the small piston would cause what pressure to be exerted upon the end of the large piston?

THE BUOYANCY OF LIQUIDS.

☞ A cubic centimetre of water weighs one gramme.

20. A body weighs 50 kilogrammes in air, and has a bulk of 40 cubic decimetres. How much does it weigh in water?

21. A stone weighs 80 kilogrammes in the air, and 55 kilogrammes in water. What is its bulk?

22. A hollow vessel of copper weighs one kilogramme. What must be its bulk in order that it may just float in water?

23. A hollow vessel of iron weighs 15 kilogrammes. What must be its bulk in order that it may sink one half in water?

24. A boat displaces 12 cubic metres of water. What is its weight?

SPECIFIC GRAVITY.

25. A body weighs 150 hectogrammes in air, and weighs 2 kilogrammes in water. What is the weight of a bulk of water equal to that of the body?

26. A flask full of water weighs 62 grammes: a piece of lead weighs 44 decagrammes in the air. It is put into the flask, and the flask is filled with water. It is found that the lead and water together weigh 462 grammes. What is the weight of a bulk of water equal to that of the lead?

27. A piece of lead weighs 56 grammes in the air, and 51 grammes in water. What is the specific gravity of lead?

28. A flask holds 75 grammes of water: a lump of copper, which weighs 160 grammes in the air, is put into the flask, and it is found that the water and the copper together weigh 219 grammes. What is the specific gravity of copper?

29. The specific gravity of iron is 7.8. What weight of water will 45 kilogrammes of iron displace?

30. The specific gravity of zinc is 7.2. What is the bulk of 90 kilogrammes of zinc?

31. A piece of wood, which weighs 25 grammes in the air, is fastened to a piece of iron whose weight is 80 grammes; and on immersing both in water and weighing them, it is found that they together weigh 45 grammes. What is the weight of the water displaced by the wood?

32. A piece of wood, weighing 42 grammes, is fastened to a piece of zinc weighing 86 grammes, and both are weighed under water, and are found to weigh 34 grammes. What is the specific gravity of the wood?

33. A flask weighing 20 grammes weighs 430 grammes when full of water, and 5555 grammes when full of mercury. What is the specific gravity of mercury?

34. A hydrometer weighing 50 grammes requires a weight of 80 grammes to sink it to the neck in water, and a weight of 135 grammes to sink it to the same depth in sulphuric acid. What is the specific gravity of sulphuric acid?

35. A vessel holds 100 kilogrammes of water. How much mercury would it hold?

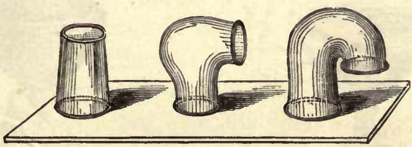
36. How much alcohol will it hold, if the specific gravity of alcohol is .79?

THE PRESSURE OF GASES.

27. *Gases have Weight.* — Weigh very carefully a thin copper globe when filled with air; then exhaust the air from it by means of the air-pump, and again weigh it. It will be found to weigh less in the last case than at first. This shows that air has weight. In like manner, it may be shown that all gases have weight.

28. *Gases, like Liquids, press upward, downward, and sideways.* — Fasten over the mouth of a bell-jar, open at both ends (Figure 25), a piece of india-rubber, and place

Fig. 25.



the bell-jar on the plate of the air-pump, and exhaust the air from under the rubber. The rubber will be forced into the jar, showing the downward pressure of the air. If a bell-jar, with its mouth at the side, be closed, as before, with a piece of india-rubber, on exhausting the air from the jar the rubber is forced into it. This shows the lateral pressure of the air. If the neck of the jar is bent around still farther, so that it shall open downward, and the mouth is closed as before, on exhausting the air the rubber is forced into the jar. This shows the upward pressure of the air.

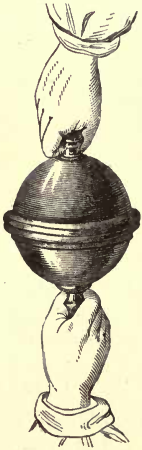
29. *The Hand-Glass.* — If the first bell-jar in Figure 25 is small enough at the top to be covered with the palm of the hand, and the air be exhausted from it when thus covered, the hand will be held down with considerable force by the pressure of the air upon it.

If a wet bladder be tied over the same bell-jar and dried, and the air be exhausted as before, the bladder will burst with a loud noise. These two experiments show the downward pressure of the air.

30. *The Magdeburg Hemispheres.* — Figure 26 represents

Fig. 26.

Fig. 27.

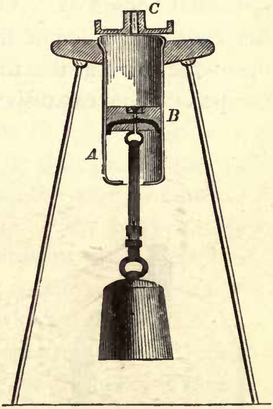


two brass hemispheres, some four inches in diameter, the edges of which are made to fit tightly together. The whole can be screwed to the air-pump by means of the stopcock at the bottom. While the hemispheres contain air, they can be separated with ease, since the outward pressure is just balanced by the inward pressure; but when the air within is pumped out, it is very hard to pull them apart. Since it is equally difficult to do this, in whatever position the hemispheres are held, the experiment shows that the air presses in all directions.

This piece of apparatus is called the *Magdeburg Hemispheres*, from Otto von Guericke, of Magdeburg, by whom it was invented.

31. *The Weight Lifter.* — In Figure 28, *A* is a strong glass cylinder, open at both ends; *B* a piston, working air-tight within it; and *C* a brass plate, covering it closely, and having a hole in the centre to which a hose may be screwed for connecting it with the air-pump. When the air is exhausted from the cylinder, the piston rises, even if a heavy weight is hung from it as shown in the Figure.

Fig. 28.



This experiment affords a very striking illustration of the upward pressure of the air.

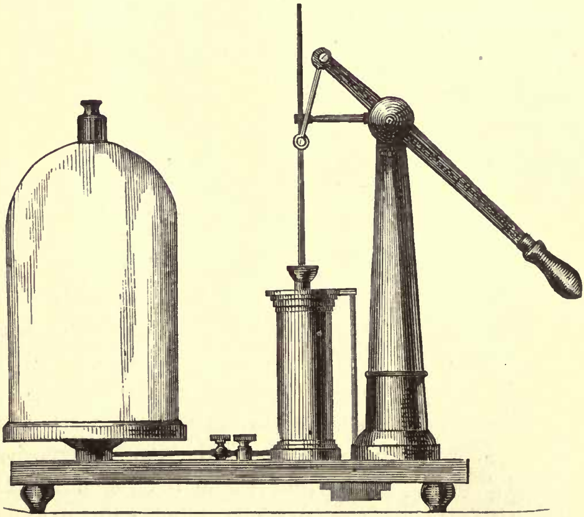
32. *The Expansive Force of Gases.* — If an india-rubber bag, partially filled with air, be closed air-tight and placed under the receiver of the air-pump, the bag fills out, as shown in Figure 29, when the air is exhausted from the receiver. The same would be true if the bag were partially filled with any gas. All gases then tend to expand.

Fig. 29.

33. *The Air-Pump.* — An instrument for removing the air from a vessel is called an air-pump. One form of such a pump is shown in Figure 30. It consists of a cylinder, in which a piston moves air-tight. In this piston is a valve opening upward. At the top of the cylinder is another valve also opening upward. The bottom of the cylinder is connected with the pump-plate by means of a tube. On this plate is placed the vessel from which the air is to be exhausted. This vessel is called the *receiver*. The piston is worked by means of the handle.

As the piston is forced down the expansive force of the air below pushes open the valve in the piston to get into the space left behind it. When the piston is drawn up again the expansive force of the air above closes this valve and opens the valve at the top of the cylinder, so that this air escapes. The expansive force of the air in the tube

Fig. 30.

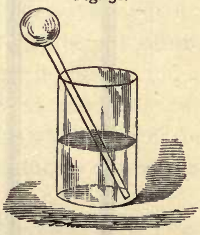


and receiver causes it to fill the space behind the piston. When the piston is again pushed down, the downward pressure of the air outside closes the valve at the top of the cylinder, while the expansive force of the air below opens the valve in the piston, and some of the air passes through it. On drawing up the piston again this air is removed as before. By continuing this process the air is nearly all withdrawn from the receiver. It cannot be wholly withdrawn, because as it becomes more and more exhausted, the expansive force becomes less and less, until at last it is not sufficient to open the valve in the piston.

34. *A Body is buoyed up in the Air.* — If a hollow sphere be balanced in the air by a piece of lead, and then the whole apparatus be put under the receiver of an air-pump and the air exhausted, the lead will no longer balance the sphere. This shows that a body is buoyed up in the air as well as in a liquid (22). Bodies seem to be lighter in the air than in a *vacuum* (that is, a space from which the air has been exhausted), for the same reason that a body seems lighter in water than in the air. The upward pressure of the air upon the bottom of the body is somewhat greater than the downward pressure upon the top of the body. A body in the air, then, is buoyed up by a force just equal to the weight of the air which it displaces. If a body weighs more than the air it displaces, it sinks through the air; if it weighs less than the air it displaces, it rises in the air.

35. *Balloons.* — Balloons rise in the air because they are filled with some substance which makes them lighter than the air which they displace.

Fig. 31.



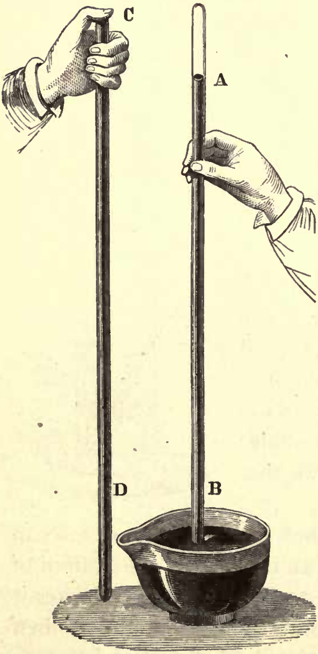
If a glass bulb and tube filled with air be arranged, as in Figure 31, with the end of the tube under water, and the bulb be heated by means of a lamp, the air in it expands, and a part of it is driven out in bubbles through the water. This shows that air expands when heated.

Paper balloons are sometimes made which are sent up by fastening a light just under an opening in the bottom of the balloon. The light heats the air inside, and causes it to expand, and a part to pass out. The remainder is then lighter than the air displaced by the balloon, and it consequently rises. Large balloons are made of strong silk, and filled with some very light gas, such as coal gas. This makes the balloon so much lighter than the air it displaces, that it will rise, carrying a car with two or three persons in it.

Balloon ascensions are now quite common, and it is possible that the time will come when by their aid we may navigate the air as we now navigate the sea. As yet, however, it has been found impossible to guide them. When once in the air they are at the mercy of the wind, and go in whichever way it happens to be blowing.

36. *The Atmospheric Pressure will sustain a Column of Liquid in an inverted Vessel.* — If a glass jar be filled with water and inverted in a dish of water, care being taken to keep the mouth of the jar all the time under water, the liquid will not flow out of the jar when it is raised. If, however, the jar be partially filled with water, and inverted in a shallow dish of water, and placed under the receiver of an air-pump, and the air be exhausted, the water will flow out from the jar; showing that it is the pressure of the atmosphere on the surface of the water in the dish which keeps the water in the inverted jar. If mercury or alcohol is used instead of water, the result is the same.

Fig. 32.



37. *The Atmospheric Pressure will sustain a Column of Mercury about* 30 *Inches high.*—If a glass tube closed at one end and about 34 inches long be filled with

mercury, and inverted in a cup of mercury, as shown in Figure 32, a part of the mercury will run out, leaving a column about 30 inches high in the tube.

38. *The Atmospheric Pressure is equal to about* 15 *Pounds to the Square Inch.* — Suppose the tube in the above experiment were one inch square, it follows, from the way in which liquids press, that the downward pressure at the bottom of the tube would be just equal to the downward pressure of the atmosphere on each square inch of the surface of the mercury in the vessel.

If now we weigh the mercury in the tube, we shall find that there are about 15 pounds of it. This column of mercury then exerts a pressure of 15 pounds at the bottom of the tube. The air then presses with a weight of 15 pounds upon every square inch of surface. We do not perceive this great pressure, because the air presses equally in every direction.

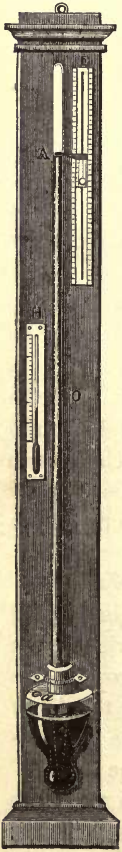
39. *The Atmospheric Pressure varies from Day to Day.* — If a glass tube be filled with perfectly pure mercury, so that it shall not become tarnished, and then inverted in a cup of mercury and left standing, and the height of the mercury column noted from day to day, it will be found to vary considerably, being sometimes as much as two inches higher than at other times. This variation in the height of the mercury column must be due to changes in the pressure of the air.

40. *The higher the Place, the less the Atmospheric Pressure.* — If the height of the mercury in the tube be noticed at the base of a mountain, and it be then carried to the top of the mountain and the height of the mercury again noticed, it will be found considerably less in the latter case. This shows that the atmospheric pressure becomes less, the higher we go above the surface of the earth.

The atmosphere is a great ocean of air which surrounds the earth, and at the bottom of which we live, as the fishes live at the bottom of the sea. The changes in the height of the mercury just described show that the pressure increases with the depth. The daily variations in the pressure are probably due to large waves which run over the surface of this ocean.

41. *The Barometer.* — An instrument for measuring the pressure of the atmosphere is called a *barometer.* One form of it is shown in Figure 33. It consists of a cup and tube filled with mercury, as in the experiment illustrated by Figure 32. These are fastened to a wooden frame. At the upper part of the tube there is a scale with a sliding index, for measuring the height of the mercury. *H* is a thermometer.

Fig. 33.



The mercury is often put into a leather bag instead of an open cup as here, since it is less likely to be spilled. As the leather is flexible the pressure of the air is brought to bear upon the mercury through the bag.

42. *Uses of the Barometer.* — It has already been stated that the atmospheric pressure is less as the height above the earth is greater. When we have found at what rate it diminishes, we can readily find the height of mountains by means of the barometer. We have to find the difference between the readings of the barometer at the level of the sea and at the top of the mountain. This shows how much the pressure has diminished, and from this we can find the height of the mountain.

The barometer is also of considerable use in indicating the approach of storms, especially of violent winds. It has been observed that such storms are very likely to occur immediately after a sudden diminution of atmospheric pressure, which is shown by a rapid fall of the mercury in the barometer tube. On the other hand, a gradual rise of the mercury in the tube usually indicates the approach of fair weather.

The mere height of the mercury in the tube tells us little about the weather, but a careful study of the *movements* of the mercury enables us to judge pretty accurately what changes are likely to occur in the weather.

43. *Pumps.* — As water is somewhat more than thirteen times lighter than mercury, the pressure of the atmosphere will sustain a column of this liquid about thirteen times thirty inches in height, or considerably more than thirty feet. If the tube is open at the top it is necessary to remove the air from it before the water will rise into it. An instrument for raising water in this way is called a *pump.*

The common *lifting-pump* is shown in Figure 34. It is really an air-pump, with piston and valves like those described above (33), and it works in the very same way. When the piston *P* is forced down, the air below it, by its expansive force, opens the valve *O,* through which it escapes. When the piston is drawn up again, the valve *O* is kept shut by the pressure of the air above, and the air in *A* expands, pushes open the valve *S,* and rushes into the vacuum above. The air being thus partly removed from *A,* the pressure of the air upon the water in the well outside is greater than that inside the pipe, and consequently forces the water up the pipe and through the open valve *S.* When the piston is pushed down again, the pressure of the water in the cylinder shuts the valve *S,* and opens the valve *O.* The water thus gets above the piston, which on going up again lifts it so that it flows out at the spout, as shown in the figure.

Figure 35 represents the *force-pump.* In this pump the piston *P* is solid. When it is drawn up, the water below by its upward pressure opens the valve *S* and fills the

Fig. 34.

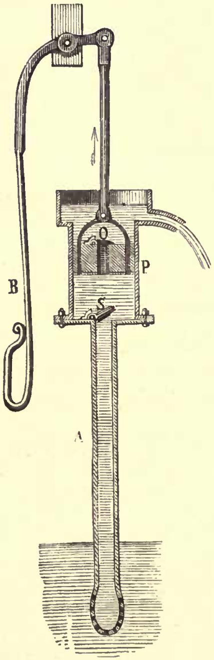
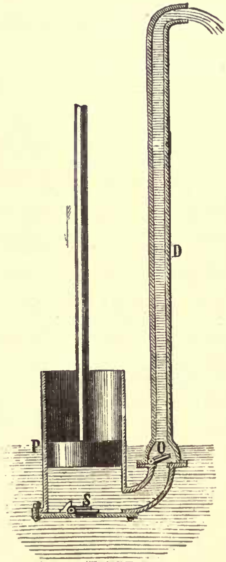


Fig. 35.



cylinder. When the piston is pushed down, the valve *S* being shut by its own weight and the pressure of the water upon it, the water is forced up through the valve *O* into the pipe *D*. When the piston goes up again, the valve *O* is closed by its own weight and that of the water above, the valve *S* opens, and the cylinder is filled as before.

In Figure 36 we have these two pumps combined. The air is pumped out through the valves *S* and *O*, and the water is forced up into the cylinder through the pipe *A* and the valve *S*, just as it was in the lifting.pump; and the water is then forced through the valve *O* and the pipe *D*, as in the force-pump just described.

In both these forms of force-pump the water is driven out of the pipe *D* only when the piston is going down. It may be made to flow out in a steady stream by adding an air-chamber above the valve *O*, as shown in Figure 37. As

Fig. 36.

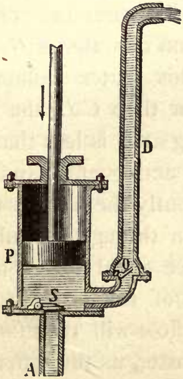
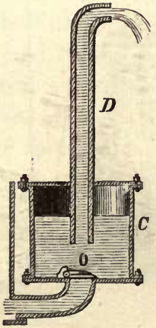


Fig. 37.



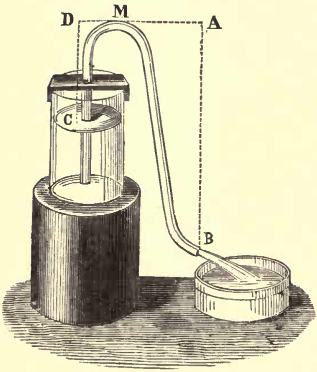
the water is forced into this chamber it compresses the air, which by its expansive force exerts a continuous pressure on the water, and drives it in a constant stream up the pipe.

In the *fire-engine*, two force-pumps are usually connected with one air-chamber. The pumps are so arranged that the piston of one is going down while that of the other is going up, thus forcing water into the air chamber all the time.

44. *The Siphon.* — Bend a tube into the form of the letter *U*, making one arm somewhat longer than the other; fill it with water, and close each end with the fingers; then invert it and place the short end under the surface of water in a vessel. If now both ends are opened, the water will flow out of the vessel through the tube. A bent tube used in this way is called a *siphon*.

To explain the action of a siphon, let us suppose it filled and the short arm placed in the water. The pressure then acting on *C* (Figure 38), and tending to raise the water in the tube, is the atmospheric pressure *less* the weight of the column of water *C D*. In like manner, the pressure on the end of the tube *B* is the atmospheric pressure *less* the pressure of the column of water *A B*. But as this latter column is longer than *C D*, the force acting at *B* is less than the force acting at *C*, and consequently the water will be driven through the tube by a force equal to the difference of these two forces. The flow will therefore be the faster, as the difference of level between *C* and *B* is greater.

Fig. 38.



45. *Tantalus's Cup.*—This is a glass cup, with a siphon tube passing through the bottom, as shown in Figure 39. If water be poured into the cup, it will rise both inside and outside the siphon until it has reached the top of the tube, when it will begin to flow out. If the water runs into the cup less rapidly than the siphon carries it out, it will sink in the cup until the shorter arm no longer dips into the liquid and the flow from the siphon ceases. The cup will then fill again as before; and so on.

Fig. 39.

In many places there are springs which flow at intervals, like the siphon in this experiment, and whose action may be explained in the same way. A cavity under ground may be gradually filled with water by springs, and then emptied through an opening which forms a natural siphon. In some cases of this kind the flow stops and begins again several times in an hour.

46. *The Air-Gun and the Condenser.*—We have seen that gases exert an expansive force which increases when they are heated (35). It increases also when they are compressed into smaller space. This is illustrated by the *air-gun*, which consists of a tube connected by a stop-cock with a small air-tight vessel of very great strength. If a large amount of air be forced into this vessel, and the stop-cock be then opened, the expansive force of the confined gas will drive a bullet from the tube as if it were fired from a musket.

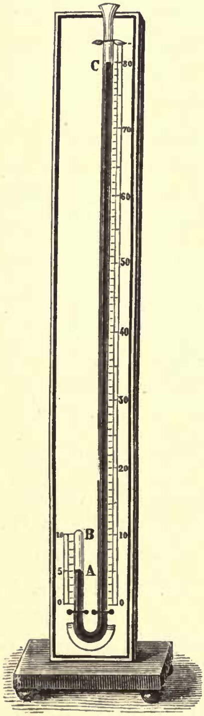
The firing of a musket is in fact another illustration of the very same kind. When the gunpowder is set on fire it forms an immense amount of gas, which, being condensed into a small space, has a very great expansive force, and therefore exerts a very great pressure upon the bullet.

An instrument used for compressing air in this and other experiments is called a *condenser*. It consists of a strong cylinder with a piston and valves arranged precisely as in the force-pump in Figure 35. It works too in the same way as the force-pump; the air rushing in through the valve *S* when the piston is raised, and being driven out through the valve *O* when the piston is pushed down. The vessel into which the air is to be forced is screwed to the pipe *D*.

47. *Mariotte's Law.*—In Figure 40 we have a long glass tube closed at one end and bent up into the form of the letter *U*. Pour in a little mercury, and tip the tube a little, so that a part of the air may escape from the closed end, and the mercury may stand at the same level in both arms. The column of air in the closed arm is now evidently under a pressure equal to that of the atmosphere,

which we have seen to be equal to that of a column of mercury 30 inches high (37). If now mercury be poured into the long arm until its level in that arm is 30 inches above that in the short arm, the air in this arm will be under a pressure of two atmospheres, or 30 pounds to the square inch. Under this pressure it will be seen that the column of air is just half as long as it was before. If more mercury be poured in, until its level in the long arm is 60 inches above that in the short arm, then the air in the short arm will be under a pressure of three atmospheres, or 45 pounds to the square inch; and it will be found to be only one third as long as at first. When, therefore, the pressure upon a column of air is doubled, the bulk is reduced to one half; when it is trebled, the bulk is reduced to one third; and so on.

Fig. 40.

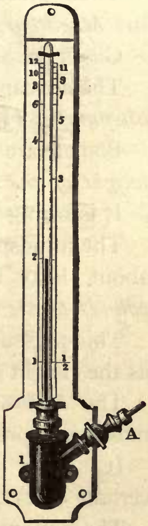


The fact that the bulk of a gas becomes less just in proportion as the pressure upon it becomes greater, or, in other words, that *the volume of a gas is inversely as the pressure which it bears*, is called *Mariotte's law*, from its discoverer.

In the above experiment, it is evident that when the bulk of the air has been reduced to one half, its expansive force, or its *elasticity*, has been doubled, since it balances double the pressure in the long arm that it did before. When its bulk is reduced to one third, it balances thrice the pressure; and so on. The elasticity of a gas then becomes greater just in proportion as its bulk becomes less, or as the pressure upon it becomes greater; or, in other words, *the elasticity of a gas is inversely as its volume, and directly as the pressure which it bears.*

48. *The Manometer.* — An instrument for measuring the expansive force, or pressure, of a gas is called a *manometer.* One form of the manometer is shown in Figure 41. It consists of a glass tube closed at the upper end and filled with air. Its lower end is fastened into a small iron box containing mercury. The tube *A* serves to connect the box with the closed vessel holding the gas whose expansive force is to be tried. The height to which the mercury is raised by the pressure of the gas is shown by a scale.

Fig. 41.



49. *The Spirit Level.* — If a tube be filled with liquid except a mere bubble of air, and then closed, this bubble will always rise to the highest part of the tube, in whatever position it may be placed. Advantage is taken of this fact in the construction of the *spirit level.*

The most common form of this instrument (Figure 42) consists of a closed glass tube, *AB*, very slightly curved on the upper side. It is filled with spirit, with the exception of a bubble of air which tends

Fig. 42.

to rise to the highest part of the tube. It is placed in a case *CD*, which is so arranged that when it is placed on a perfectly level surface the bubble of air is exactly in the middle of the tube, as represented in the figure.

SUMMARY.

Gases have *weight*. (27.)

Gases, like liquids, *press upward*, *downward*, and *sideways*. (28.)

These pressures of gases are illustrated by the *hand-glass*, the *Magdeburg hemispheres*, and the *weight-lifter*. (29–31.)

Gases are acted upon by an *expansive force*. (32.)

The air can be exhausted from a vessel by means of the *air-pump*. (33.)

Bodies are buoyed up in air by a force equal to the *weight of the air which they displace*. (34.)

It is owing to this that *balloons* rise in the air. (35.)

The atmospheric pressure balances a column of mercury about thirty inches high, and is equal to about *fifteen pounds to the square inch*. (37, 38.)

This pressure varies from day to day, and becomes less as the height of the place increases. (39, 40.)

The *barometer* is an instrument for measuring the atmospheric pressure. (41.)

It is used in finding the height of mountains, and, to a certain extent, it indicates changes of the weather. (42.)

The action of *pumps* is to be explained by the pressure of the atmosphere. (43.)

The *siphon* also acts by reason of the atmospheric pressure. (44.)

The expansive force, or *elasticity*, of gases is increased by *heat* and by *pressure*. (46.)

The bulk or volume of a gas is in the inverse ratio of the pressure which it bears.

The elasticity of a gas is in the inverse ratio of its volume, or the direct ratio of the pressure it bears.

These facts are known as *Mariotte's law*. (47.)

The elasticity of gases is measured by means of the *manometer*. (48.)

PROBLEMS.

WEIGHT OF GASES.

☞ The *specific gravity* of a gas is its weight compared with that of an equal bulk of atmospheric air.

37. A glass globe of the capacity of one litre weighs 83 grammes after the air has been exhausted from it; and 84.292 grammes when full of air. What is the weight of 1 litre of air?

38. The same globe, when full of ammonia gas, weighs 83.759 grammes. What is the weight of a litre of ammonia gas?

39. The same flask, when full of carbonic acid, weighs 84.964 grammes. What is the weight of a litre of carbonic acid?

40. The same flask, full of hydrogen, weighs 83.089 grammes. What is the weight of a litre of hydrogen?

41. The same flask, when full of oxyyen, weighs 84.428 grammes. What is the weight of a litre of oxygen?

42. What is the specific gravity of ammonia gas? What is the specific gravity of carbonic acid? What is the specific gravity of hydrogen? What is the specific gravity of oxygen?

43. A vessel of the capacity of 985 litres would hold how many grammes of air? Of carbonic acid?

44. A vessel of the capacity of 416 litres would hold how many grammes of hydrogen? Of oxygen?

PRESSURE CAUSED BY THE WEIGHT OF GASES.

☞ The atmospheric pressure is about one kilogramme upon every square centimetre of surface at the level of the sea.

45. The body of an ordinary-sized man has a surface of about 16,000 square centimetres. How many kilo-

grammes of pressure does the atmosphere exert upon a man's body? How many pounds avoirdupois?

46. A room is 12 metres long, 9 metres wide, and 5 metres high. How many kilogrammes of pressure does the atmosphere exert upon the floor of the room? How many pounds?

47. How many kilogrammes of pressure does it exert upon each end of the room?

48. How many on each side?

49. How many kilogrammes of air does the room contain?

50. The atmospheric pressure will balance a column of mercury 76 centimetres high, and the specific gravity of mercury is 13.5. It will balance a column of water how many centimetres high? How many feet high?

51. If water is to be raised 1,200 centimetres high by means of the lifting pump, how much of this distance must the water be lifted?

52. Water is to be carried over a hill 1,350 centimetres high. Can it be done by means of the siphon? Why?

BUOYANCY OF GASES.

53. A block of wood has a bulk of 900 cubic metres. How much is it buoyed up in the air?

54. A balloon when filled with gas weighs 500 kilogrammes. How many litres of bulk must it have in order that it may just float in the air?

55. A balloon has a bulk of 1,000 cubic metres, and weighs 25 kilogrammes. It is filled with coal gas, whose specific gravity is .6. By how many kilogrammes of pressure is it forced upward? If a car, which, with all its fixtures, has a bulk of 3 cubic metres and weighs 48 kilogrammes, be attached to the balloon, with what pressure will the whole be forced upward?

II.

MOTION.

We have now studied somewhat the pressures produced by gravity and other forces acting upon the three states of matter. We have seen that when a stone is held in the hand it presses upon it; and it is well known that on removing the hand the stone falls to the ground. We are now to study the *motions* caused by gravity and other forces.

FIRST LAW OF MOTION.

It is a well-known fact that a stone or other body, when at rest, will not begin to move of itself, but only on the application of some force. It is equally well known that when any body, such as a ball, is in motion, it requires some force to stop it.

50. *A moving Body when left to itself will always move in a straight Line and at the same Rate.*—If a heavy weight, such as a lead ball, be suspended from a point by means of a string or a wire, and it be set swinging, it will swing for a time and then come to rest. A ball thus suspended is called a *pendulum*. If this pendulum be placed under the receiver of an air pump, and the air partly exhausted, it will swing a longer time; and the more the air is exhausted the longer the pendulum will swing. If the pendulum be nicely hung, so that there will be very little friction at the point on which it turns, it will, when once set going in an exhausted receiver, swing 24 or 30 hours. Since the length of the time that the pendulum will swing increases as the resistance it meets diminishes, we conclude that it would swing forever, provided there were no resistance to its mo-

tion. Now, mathematicians have found that they can explain this swinging of the pendulum by supposing that the ball of the pendulum, when once put in motion, would move on forever in a straight line and at the same speed, were it not acted upon by any other force. They have found, moreover, that this is the only way in which they can explain the motion of the pendulum.

We conclude, then, that a moving body when left to itself will always move in a straight line and at the same rate. This is usually called the *first law* of *motion.*

The inability of a body, whether at rest or in motion, to change its state, is often called *inertia.*

51. *An unbalanced Force must act upon a Body in order to put it in Motion, or to change the Direction or the Rate of its Motion.* — A ball held in the hand remains at rest, because the downward pull of gravity upon the ball is just balanced by the resistance offered by the hand. If the hand is removed so that the force of gravity is unbalanced, then the ball begins to move. If we push with the hands against the opposite sides of a book, the book will remain at rest as long as the push of one hand is just balanced by that of the other. Take away one hand, so that there shall be nothing to balance the push of the other, and the book begins to move. So, in every case, a body begins to move only when an unbalanced force acts upon it.

And when a body is once in motion, it changes the direction and rate of its motion only when an unbalanced force is acting upon it. When a body is once in motion it is just as natural for it to continue to move in a straight line, with uniform speed, as it is for it to remain at rest when once it is at rest. It seems to us more natural for a body to be at rest, because, when a body is put in motion at the surface of the earth, it always meets with resistance which quickly brings it to rest again, unless the moving force continues to act upon it.

52. *The Effect of a Force acting for a Moment only.*— When the moving force acts upon a body only an instant, as when a ball is struck with a bat, or a bullet is fired from a gun, it has its greatest speed at first, and its motion is gradually wasted by the resistance it meets in passing through the air or over the earth.

53. *The Effect of a Force acting continuously.*—When, however, a body is acted upon continuously by a force, as in the case of a railway train or a steamboat, the motion, slow at first, gradually increases till it reaches a certain point, when the speed remains unchanged so long as the moving force is unchanged. When the moving force is increased the speed increases, and when it is diminished the speed diminishes.

54. *The Resistance a Moving Body meets increases as the Square of its Velocity.*—The steamboat in moving has to push aside a certain amount of water in a second, and this is the chief resistance it meets. Now, as the speed of the boat increases, more water must be pushed aside in a second, and each particle of water must be moved aside more quickly. Hence, the faster it moves, the greater the resistance. Suppose the speed of the boat to be doubled, twice as many particles of water must be pushed aside in a second, and each particle must be pushed aside in half the time. Hence, the resistance becomes fourfold when the velocity is doubled. The resistance, then, increases as the square of the velocity. This explains the fact that, in order to double the speed of a steamboat, the power of the steam must be quadrupled, and in order to treble the speed the power must be increased ninefold. The same is true in the case of the train of cars, or of any moving body. When their velocity is doubled, they meet resistance at twice as many points in a second, and the resistance at each point must be overcome in half the time.

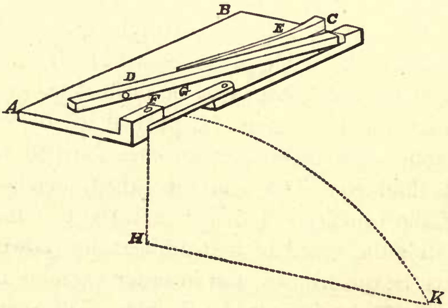
55. *A moving Body may be in Equilibrium.*—We have seen

(11) that a body at rest is in equilibrium. It is so because the forces acting upon it are balanced. In the case of a train of cars, on first starting the force of the steam is not wholly balanced by the resistance; hence it imparts motion to the train. But as the speed of the train increases, the resistance also increases, until it finally equals the force of the steam. All the force of the steam is now used in balancing the resistance, and the speed no longer changes. Since the two forces acting upon the moving body balance each other, it must be in equilibrium. Every body then moving in a straight line and with uniform speed is in equilibrium.

SECOND LAW OF MOTION.

56. *A Force has the same Effect in producing Motion, whether it acts upon a Body at Rest or in Motion, and whether it acts alone or with other Forces.* — In Figure 43, *A B* is a board;

Fig. 43.



C D an arm moving upon it, turning on a hinge at *C*, and driven by a spring *E*; at the end of the arm *D* is a hollow, with its opening in the side of the arm large enough to contain a small ball, so that when the arm is driven by the spring *E*, the ball will be thrown horizontally; at *F* is another chamber opening downwards, the lower opening being closed by the board *G*, which will be knocked away by a blow of the arm *CD*. If a ball be put in the chamber at *D*, and another in the chamber at *F*, the very same movement which throws the first horizontally forward will let the second drop at the same instant. On trying the experiment it will be found that both balls will reach the floor exactly together. So, too, if the machine and floor are both inclined at just the same angle, the balls will both reach the floor together.

In the case of the ball that is thrown horizontally, two forces have acted, one to throw it forward in a straight line, and the other to draw it to the earth in a straight line; and it is seen that it is drawn just as far towards the earth in a given time as the ball that was let fall from a state of rest.

From this and other experiments it has been found that, when two forces acting in different directions have been brought to bear upon a body so as to produce motion, the body at any given time will be just as far from the place it would have reached had only one of the forces acted upon it, as it would have been had it been at rest at this point, and acted upon by the other force alone for the same time.

For example, suppose the spring would send the ball forward 30 feet in a second, and the force of gravity pulls it from a state of rest 16 feet towards the earth in the same time, the ball at the end of the second will be just 16 feet below the point it would have reached had only the force of the spring acted upon it. So, were a ball thrown directly upward with a velocity of 100 feet a second, at the end of the second it would be only 84 feet high, that is, 16 feet below the point it would have reached had not the force of gravity acted upon it. If it were thrown directly downward from the top of a high tower with the same velocity, it would be at the end of a second 116 feet below the top of the tower, that is, 16 feet below the point it would have reached had not gravity acted upon it. Now 16 feet is just the distance in each of the above cases that gravity would have pulled the ball in a second from a state of rest.

Again, suppose that the current in a stream is strong enough to carry a boat down stream one mile in an hour, and a person attempts to row the boat directly across the stream at a rate which would take him across in an hour, at the end of the hour the boat would be at the opposite bank just a mile down stream.

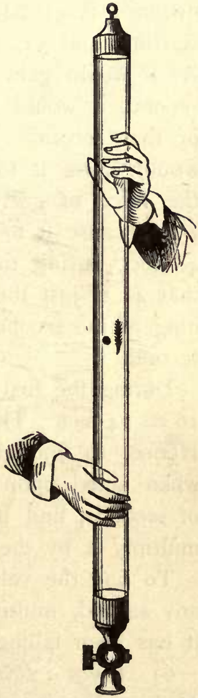
57. *A Body thrown horizontally or obliquely when acted upon by Gravity describes a curved Path.* — When both the forces acting upon the body are instantaneous, it moves in a straight line; when one is instantaneous and the other continuous, as in the case of gravity acting on a ball thrown horizontally or obliquely, the path is curved. The curved path described by a body when acted upon by an instantaneous and a continuous force is well illustrated by a jet of water issuing from the side of a vessel. The lateral pressure is the instantaneous force acting upon each particle of water as it issues from the opening; and the force of gravity acting upon it after it leaves the opening is the continuous force. The curved path in this case is called a *parabola*.

On account of this effect of gravity upon a body moving horizontally or obliquely, a cannon-ball describes a curved path. If then a cannon or a musket is fired at a distant object, it must be aimed above it.

We have a good illustration of the second law of motion in the case of falling bodies.

FALLING BODIES.

Fig. 44



58. *All Bodies would fall at the same Rate, were it not for the Resistance of the Air.* — As we see bodies light and heavy falling through the air, we come to think that the force of gravity causes heavy bodies to fall more rapidly than light ones; but if we place a coin and a feather in a long glass tube and exhaust the air completely, on inverting the tube (Figure 44) the two bodies will fall through it in the same time. It must be therefore the resistance of the air which causes a lighter body to fall more slowly through the atmosphere than a heavy one does.

When therefore the force of gravity is unimpeded in its action, it will cause every body, whatever may be its size, shape, or density, to fall with exactly the same speed.

59. *When a Body is moving directly downward Gravity increases its Velocity at the Rate of 32 Feet a Second.* — It is found by means of a pendulum that a body falls 16 feet the first second, and acquires a velocity of 32 feet during the time. As gravity has the same effect upon a moving body as upon one at rest, a falling body will gain in velocity 32 feet each second. When therefore a body is moving directly downward, gravity increases its velocity at the rate of 32 feet a second.

60. *How to find the Distance a Body falls in a given Time.* — As we have seen, a body when falling from a

state of rest has a velocity of 32 feet at the end of the first second, and falls 16 feet during that second. This distance is exactly the mean between 0, its velocity at starting, and 32, its velocity at the end of the second. As it would gain a velocity of 32 feet during the next second, it would have a velocity of 64 feet at the end of that second. The velocity it has already acquired would cause it to fall 32 feet the second second, and the force of gravity acting upon it during that time would cause it to fall 16 feet more; hence it would fall 48 feet during the second second. It will be noticed that 48 is just the mean of 32, its velocity at the beginning of the second, and 64, its velocity at the end of the second.

During the first two seconds the body would fall $48 + 16 = 64$ feet. This is just twice the mean of 0 and 64. Hence, to find the distance that any body would fall when acted upon by gravity alone during any number of seconds, find its mean velocity during the time, and multiply it by the number of seconds.

To find the velocity of a falling body at the end of any second, multiply 32 feet by the number of seconds it has been falling.

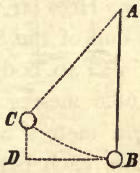
61. *When a Body is moving directly upward Gravity retards its Velocity at the Rate of* 32 *Feet a Second.* — We have already seen that gravity has the same effect on a body in motion as on one at rest. Since, then, it causes a body in falling from a state of rest to acquire a velocity of 32 feet a second, it must, in the case of a body moving directly upward, diminish its velocity at the rate of 32 feet a second. And it must also cause it to rise each second 16 feet less than if it were not acting upon it.

62. *How to find the Distance a Body, when thrown upward, will rise in a given Time.* — To find this distance, take the mean velocity of the body during the time, and multi-

ply it by the number of seconds. To find the velocity at any particular second, multiply the number of seconds the body has been rising by 32, and subtract this from the velocity the body has at starting.

63. *A Body always acquires the same Velocity in falling the same Distance.* — It has been found that a body in rolling down an inclined plane (allowance being made for friction) acquires the same velocity that it would have acquired in falling a distance equal to the height of the inclined plane. So, too, in the case of a pendulum-ball, if it be drawn up to the point *C* (Figure 45), and then allowed to fall to *B*, it will, on reaching *B*, have the same velocity it would have had in falling from *C* to *D*. And it is found to be true in general, that bodies always acquire the same velocity in falling the same distance from a state of rest, no matter what path they may take.

Fig. 45



PROBLEMS.

SECOND LAW OF MOTION.

☞ Gravity causes a body to fall from a state of rest 4.9 metres in a second, and increases its velocity 9.8 metres in a second.

56. A body falls from a state of rest. How many metres of velocity has it at the end of the third second?

57. A body is thrown downward with a velocity of 50 metres a second. What will be its velocity at the end of 7 seconds?

58. A body is thrown downward with a velocity of 23 metres a second. What will be its velocity at the end of 9 seconds?

59. A body is thrown upward with a velocity of 42 metres a second. What will be its velocity at the end of 4 seconds?

60. A body is thrown upward with a velocity of 75 metres a second. What will be its velocity at the end of 5 seconds?

61. A body is thrown upward with a velocity of 98 metres a second. How long will it continue to rise?

62. How high will the above body rise?

63. How far will it rise the first 3 seconds?

64. How far will it rise the last 3 seconds?

65. How far will it rise from the beginning of the 3d to the end of the 8th second?

66. Two bodies are thrown upward, one with a velocity of 68.6 metres a second, and the other with a velocity of 137.2 metres a second. How many seconds will it be before each begins to fall?

67. To what height would each rise?

68. One ball is thrown upward with a velocity of 78.4 metres a second, and another with twice this velocity. The last ball will rise how many times as high as the first?

69. If the second ball had been thrown with thrice the velocity of the first, how many times as high would it have risen?

70. If it had been thrown with four times the velocity, how many times as high would it have risen?

71. A ball falls from a state of rest, and reaches the earth in 12 seconds. With what velocity does it strike the earth?

72. From what height did the ball in the last example fall?

73. How far did it fall the first 5 seconds?

74. How far did it fall the last 5 seconds?

75. How far did it fall from the beginning of the 3d to the end of the 5th second?

76. How far did it fall from the beginning of the 8th to the end of the 11th second?

77. A ball is thrown downward with a velocity of 125 metres a second, and reaches the earth at the end of 7 seconds. What is its velocity on reaching the earth?

78. From what height was the ball in the last example thrown?

79. Through what distance did it pass from the beginning of the 3d to the end of the 6th second?

80. A stone falls from a state of rest, and is 4 seconds in reaching the earth. With what velocity does it strike the earth? Through what distance does it fall?

81. If the stone had reached the earth in 8 seconds, what velocity would it have acquired, and through what distance would it have fallen?

82. If the stone had reached the earth at the end of 12 seconds, with what velocity would it have reached the earth, and through what distance would it have fallen?*

83. A body in falling from a state of rest through 4.9 metres acquires a velocity of 9.8 metres a second. Through what distance must it fall in order to double this velocity?

84. Through what distance must it fall in order to treble this velocity?

85. A stone falls from a height of 19.6 metres. With what velocity does it reach the earth?

NOTE. — We see from problems 80 – 85 that *the velocity of a body increases as the square root of the distance through which it falls from a state of rest.* We see from problems 66 – 70 that *the height to which a body will rise increases as the square of the velocity with which it starts.*

* See Appendix, II.

THIRD LAW OF MOTION.

64. *Momentum.* — If balls of lead of different size be placed in the cavity of the arm *CD* (Figure 43), and the arm be drawn back to exactly the same point each time, the balls will not all be thrown to the same distance. The smaller the ball the farther it will be thrown. If one ball is twice as heavy as another, it will be thrown only one half as far; if three times as heavy, only one third as far; and so on.

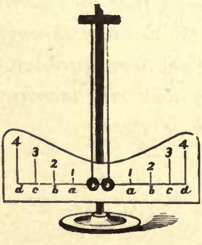
The same is true when the balls are of different materials, provided their mass is different. By the *mass* of a body we mean its quantity of matter. This is usually measured by its weight; that is, if a body weighs twice as much as another, its mass is said to be double; if thrice as much, its mass is said to be treble; and so on.

We see then that the same force acting upon bodies containing different quantities of matter does not impart to each the same velocity; and that the force acting upon each being the same, the velocity will be in the inverse ratio of the quantities of matter that they contain; that is, if the quantity of matter in each be multiplied by its velocity, the products will all be equal.

The product of the velocity of a body multiplied by its mass is called its *momentum*.

The same force, then, will impart the same momentum to a body, whether that body be large or small.

Fig. 46.



65. *A moving Body cannot impart Motion to another Body without itself losing the same Quantity of Motion.* — Hang two balls of lead or clay side by side, as shown in Figure 46, and place behind them an arc graduated so that the line 2 *b* shall be four times as

long as 1 *a;* 3 *c*, 9 times as long as 1 *a;* and 4 *d*, 16 times as long as 1 *a*.

Now, if one of the balls be drawn back to the division 2 on the scale, and dropped, it will, as we have seen, (*note*, page 57,) on reaching the other ball, acquire twice the velocity it would have acquired had it been dropped from division 1; and if dropped from division 3, it will acquire three times the velocity it would have acquired had it been dropped from 1.

If now both balls are of the same weight, and one of them be raised to the division 2 and dropped, on striking the other ball it will move on with that ball to 1. The momentum of the first ball is then sufficient to cause both balls to move on to this division. Now, to cause the balls to rise to this division, they must start with just half the velocity that the first ball had on reaching the second ball. The momentum of the balls after collision is then the same as that of the moving ball before collision. The moving ball has then imparted to the ball at rest a quantity of motion equal to half its own, and has in turn lost half its own motion.

Put now in the place of these balls two other balls of unequal size, whose joint weight shall be equal to that of the first balls, and let the weight of the smaller ball be just one third that of the larger ball. If now this ball be raised to 4 and dropped, it will acquire on reaching the larger ball twice the velocity of the ball first dropped from 2; and as its mass is just half the mass of that ball, its momentum will be the same. On allowing it to fall from 4 against the larger ball, the two will move on together to 1. But this is just the height to which the balls moved in the first experiment. The balls, then, after collision, have the same momentum that the moving ball had before collision. Since, after collision, the balls have one fourth the velocity of the smaller ball before collision, the smaller ball will have only one fourth the motion it had before, while the larger ball will have three times the motion of the smaller one, or three fourths the motion the smaller one had before collision. The smaller ball has then imparted to the larger one a quantity of motion equal to three fourths its own, and has in turn lost three fourths its own motion.

If two equal balls of ivory, or some other very elastic substance, are hung side by side, and one of them is raised and dropped against the other, on collision the first ball comes to rest, and the second ball starts off with a velocity equal to that which the first had acquired.

It is found to be true in every case that a moving body cannot impart motion to another body without itself losing the same quantity of motion. This is usually called the law of *action* and *reaction*, and stated thus: *action and reaction are always equal and in opposite directions.*

This law is the result of the inability of a moving body of itself either to increase or to lessen its quantity of motion. On meeting another body it may impart some of its own motion to it; but it cannot give motion to this body, and at the same time retain all its own motion.

66. *Other Cases of Action and Reaction.*—When any force acts in opposite directions, it is usually said to *act* in one direction, and *react* in the opposite. Thus in firing a cannon, the expansive force of the gases suddenly set free by the burning powder acts equally in all directions. It acts upon the sides with equal and opposite forces which neutralize each other unless the cannon bursts. It also acts toward the muzzle and breech with equal forces, which produce equal effects, one upon the ball and the other on the cannon, causing the recoil. The ball and the cannon both have the same momentum, but the ball, since it has a much less mass, gets a much greater velocity. This expansive force is said to *act* upon the ball and to *react* upon the *gun*. So, too, in walking, we are said to react upon the

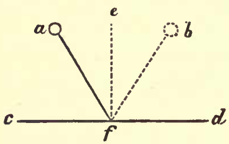
earth. The truth is, that the bent leg acts like a bent spring between our bodies and the earth, and when the spring straightens it pushes us away from the earth and the earth away from us; the earth being moved as much less than our bodies as its mass is greater.

67. *It requires Time to impart Motion to a Body as a Whole.*—The forces which impart motion to a body often act directly upon only a few of its particles. When a ball is struck by a bat, only a small part of it receives the blow, and when a bullet is shot from a gun, the gases (46) act only upon one half of it. When a body is thus set in motion by a force acting upon only a few of its particles, it is clear that the motion must be transmitted from particle to particle. Now, this transmission of motion from particle to particle requires time, although this time may be exceedingly short. If the force acts so suddenly that there is not time enough for this transmission, the part acted upon is flattened or chipped off. Thus a musket ball may be fired through a window pane, making a clear round hole without cracking the glass. If the ball had been thrown by the hand, the whole pane would have been shattered. In the first case the speed of the ball was so great that the particles in front of it had not time to transmit their motion to those about them; hence they moved on alone, leaving the others at rest. If the pane had been suspended by a fine thread, the ball would have passed through it in the same way, without breaking the thread, or causing the pane to swing in the least. So a door half open may be pierced by a cannon-ball without being shut. The end of a musket in a soldier's hand has been known to be carried away by a cannon-ball without his being aware of it. It is a well-known fact that a tallow-candle may be fired through a board, since it gets through it before the parts of the tallow have time to yield. In this way a soft missile may hit as hard as lead if fired with sufficient speed.

We see, then, that when a moving body meets with another it seldom expends all its power in imparting motion to that body as a whole, but also pierces it more or less. The power of a body to pierce another *increases as the square root of its velocity;* that is, if a body is to pierce another twice as far, it must have four times the velocity; if three times as far, nine times the velocity; and so on.

68. *Reflected Motion.* — When an elastic ball is thrown against the floor it rebounds. If it is thrown directly downward, it retraces its path in its rebound. If it is thrown obliquely, it rebounds obliquely in an opposite direction. In Figure 47, if the ball is thrown in the direction *a f*, it will rebound in the direction *f b*. If the line *e f* be drawn at right angles to the surface, the angle formed by the two lines *a f* and *e f* is called the angle of *incidence*, and is always equal to the angle formed by the two lines *b f* and *e f*. This last angle is called the angle of *reflection*. In reflected motion the *angle of incidence always equals the angle of reflection.*

Fig. 47.



SUMMARY.

A moving body, when left to itself, will always move in a straight line and at the same rate. (50.)

An *unbalanced* force must act upon a body in order to put it in motion, or to change the direction or rate of its motion. (51.)

When a force acts upon a body for a moment only, the motion which it gives it is gradually wasted away, owing to the resistance which the body meets. (52.)

The resistance which a moving body meets increases as the square of the velocity of its motion. (54.)

A body moving in a straight line and with uniform velocity is in *equilibrium*. (55.)

An unbalanced force has the same effect, whether it act upon a body at rest or in motion, and whether it act alone or with other forces. (56.)

A body thrown horizontally or obliquely, when acted upon by gravity, is made to move in a curved path. (57.)

Were it not for the air, a light body would fall as fast as a heavy one. (58.)

Gravity acting alone causes a body to fall from a state of rest about 16 feet in a second.

When a body is moving directly downward gravity increases its velocity at the rate of 32 feet a second. (59.)

When a body is moving directly upward gravity retards its velocity at the rate of 32 feet a second. (61.)

The velocity of a body increases as the square root of the space through which it falls.

The height to which a body will rise increases as the square of the velocity with which it starts. (*Note*, page 57.)

A body always gains the same velocity in falling from the same height, whether it falls directly downward or obliquely. (63.)

The same force always gives to a body the same quantity of motion.

The quantity of a body's motion is found by multiplying its weight by its velocity. (64.)

A moving body cannot impart motion to another body without itself losing the same quantity of motion. (65.)

When the same force acts in opposite directions, it is usually said to *act* in one direction and to *react* in the opposite. (66.)

It requires time to give motion to a body as a whole. (67.)

In reflected motion the angle of incidence equals the angle of reflection. (68.)

PROBLEMS.

THIRD LAW OF MOTION.

☞ To find the momentum of a body, multiply its weight in grammes by its velocity in metres.

86. A body weighs 50 kilogrammes and is moving at the rate of 12 metres a second. What is its momentum?

87. The same body is moving at the rate of 5 metres a second. What is its momentum?

88. With what velocity must a body weighing 6 grammes move, in order to have the same momentum as a body weighing 500 kilogrammes and moving at the rate of 2 metres a second?

89. A certain force gives to a body weighing 45 kilogrammes a velocity of 9 metres a second. What velocity would the same force give to a body weighing 3 grammes?

90. A body weighing 5 kilogrammes and moving at the rate of 175 metres a second meets a body at rest weighing 85 kilogrammes, and after meeting they both move on together. What is their velocity?

91. What is the momentum of the larger body?

92. What is the momentum of the smaller body, and how much momentum has it lost?

93. If the larger body had weighed 20 kilogrammes, what would have been their velocity after meeting, and how much momentum would the smaller body have lost?

94. If the second body had weighed 3 grammes, what would have been the velocity of the bodies after meeting, and how much momentum would the first body have lost?

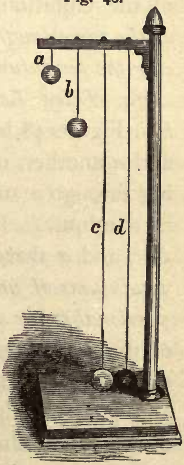
THE PENDULUM.

75. A pendulum is a heavy body hung from a fixed point by means of a cord or rod. When the centre of gravity of the body is directly under the point of support, the body remains at rest; but if the body be drawn out of this position, it will on being let go fall towards a vertical line passing through the point of support, and when it has reached this line it will, owing to its inertia, pass beyond it. On coming to rest it again falls toward this vertical line and again passes beyond, and thus continues to swing from side to side.

There are two kinds of pendulum, the *simple pendulum* and the *compound pendulum*.

76. *The Simple Pendulum.* — A *simple* pendulum consists of a material point, suspended to a fixed point by means of a thread without weight, perfectly flexible, and incapable of stretching. Such a pendulum has of course no real existence; but we can approach sufficiently near to it, for purposes of illustration, by suspending a small lead bullet to a fixed point by means of a fine silk thread.

Fig. 48.



77. *First Law of the Vibration of the Pendulum.* — Suppose *d*, in Figure 48, to be a leaden ball hanging by a fine silk thread. Pull it to one side so that it shall swing through an arc of some 3°, and count the number of its vibrations in a minute. Now bring it to rest again, and draw it to one side so that it shall swing through an arc of 2°, and again count its vibrations in a minute. Again bring the ball to rest, then cause

it to swing through an arc of 1°, and count the vibrations in a minute. In all three cases the number of vibrations in a minute will be equal.

By a *vibration* is meant the whole of the pendulum's movement in one direction. The arc through which the pendulum swings is called the *amplitude* of its vibration.

The above experiment shows that, *when the length of the pendulum remains the same, and the amplitude of the vibration does not exceed* 3°, *the pendulum always vibrates in the same time, whatever be the amplitude of the vibration.*

This singular property of the pendulum is called *isochronism*, from two Greek words signifying *equal times*, and the vibrations of the pendulum are said to be *isochronous.*

78. *The Second Law of the Vibration of the Pendulum.* — Let *d* and *c* in figure 48 be two pendulums exactly alike, except that the ball of one is lead, and of the other ivory. Let each swing through a small arc, and count its vibrations in a minute. It will be found that, making allowance for the resistance of the air, each performs the same number of vibrations in the same time. This gives the second law of the vibration of the pendulum, namely: *for pendulums of the same length, the time of the vibration is the same, whatever the pendulum may be made of.*

79. *Third Law of the Vibration of the Pendulum.* — Let *b* in Figure 48 be a pendulum one fourth the length of *c*, and *a* another, one ninth the length of *c*. Set each swinging through a small arc, and count the vibrations of each in a minute. It will be found that *b* vibrates twice as fast as *c*, and *a* three times as fast as *c*. This shows that, *for pendulums of unequal length, the time of the vibration is proportional to the square root of the length;* that is, the lengths of the pendulum being made 4, 9, and 16 times greater, the time of the vibration of the pendulum will be only 2, 3, and 4 times longer. This is the third law of the vibration of the pendulum.

80. *Fourth Law of the Vibration of the Pendulum.* — It is found that when a pendulum of a given length is placed on different parts of the earth's surface, the time of the vibrations is not always the same. Towards the poles it is found to vibrate more rapidly than at the equator. Mathematicians have shown that this is because the force of gravity is stronger at the poles. They have shown that, *in different parts of the earth, the time of the vibration for pendulums of the same length is in the inverse ratio of the square root of the intensity of gravity.* That is, if the intensity of gravity were four times as great in one place as in another, the time of the vibration of a pendulum of the same length would be half as great, and so on.

81. *The Compound Pendulum.* — The simple pendulum, as has been stated, can have no real existence. Every pendulum actually used is a *compound* pendulum, consisting of a heavy weight hung from a fixed point by means of a rod of wood or metal. The particles of such a pendulum must of course be at different distances from the point of suspension, and must therefore tend to vibrate in different times. Hence the time of vibration of the whole pendulum will not be the same as that of a simple pendulum of the same length.

The compound pendulum may be regarded as consisting of as many simple pendulums as it contains particles. If these were free to move, they would vibrate in times depending upon their distances from the point of suspension; but since they are united in one body, they are all compelled to vibrate in the same time. Consequently, the vibrations of the particles near the point of suspension are retarded by the slower vibrations of the particles below them; and, on the other hand, the vibrations of the particles near the lower end of the pendulum are quickened by the more rapid vibrations of those above them. At some point between these there must be a particle whose vibration is neither retarded nor quickened, — all the particles above having just the same tendency to vibrate faster that those below have to vibrate slower. This point is called the *centre of vibration*, and it is obvious that the time of vibration of a compound pendulum is the same as that of a simple pendulum whose length is equal to the distance of the centre of vibration from the point of suspension. This distance is the *virtual length* of the pendulum.

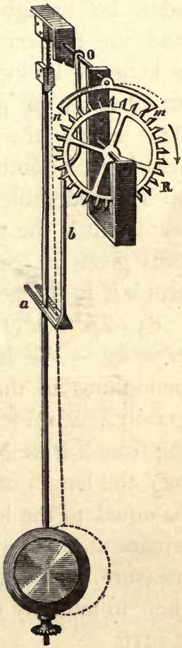
When the form of the pendulum is given, the position of the centre of vibration can be found experimentally by making use of a remarkable property of the compound pendulum, namely, that if such a pendulum be inverted and suspended by its centre of vibration, its former point of suspension will become its new centre of vibration, and the time of vibration will be the same as before. This property is usually expressed by saying that *the centres of vibration and suspension are interchangeable.*

To find the centre of vibration, then, we have only to reverse a pendulum, and by trial find the point at which it must be suspended in order to vibrate in the same time as it did before it was reversed. A pendulum constructed for this purpose is called a *reversible pendulum.*

82. *The Use of the Pendulum for Measuring Time.* — The most important use of the pendulum is for measuring time. The common *clock* is merely a contrivance for recording the beats of the pendulum, and keeping up its motion. The essential parts of such a clock are shown in Figure 49. The toothed wheel *R*, called the *scape-wheel*, is turned by a weight or spring, and its motion is regulated by the *escapement* *n m*, which swings on the axis *o*; the vibrations of the pendulum being communicated to it by means of the forked arm *a b*. When the pendulum is at rest, one of the teeth of the scape-wheel rests upon the upper side of the hook *m*, and the clock does not go. If

now the pendulum be set in motion, so that the hook *m* is moved from the wheel, the tooth which rested on it is set free, and the wheel begins to turn; but it is soon stopped by the hook *n*, which moves up to the wheel as *m* moves away from it, and catches on its under side the tooth next below. As the pendulum swings back, the hook *n* moves away, the wheel again begins to turn, but is stopped again on the opposite side by the hook *m*, which catches the tooth next to the one it held before; and thus each vibration of the pendulum allows the scape-wheel to move forward through a space equal to one half of one of its teeth. If then the wheel has thirty teeth, it will turn around once in sixty beats of the pendulum. Upon the axis of this wheel the second-hand of the clock is placed. It is connected by cogs with another wheel, which takes sixty times as long to revolve, and which carries the minute hand; and this latter wheel is connected with another, which turns in twelve times the period, and carries the hour-hand. Thus the second-hand registers the beats of the pendulum up to sixty, or one minute; the minute-hand registers the revolutions of the second-hand up to sixty, or one hour; and the hour-hand registers the revolutions of the minute-hand up to twelve, or half a day.

Fig. 49.



Were it not for the pendulum and escapement, these wheels would be whirled round very fast by the action of the weight or spring, and the clock would soon *run down*. On the other hand, were there not some means of keeping up the motion of the pendulum, it would soon be brought to rest by the resistance of the air and the friction at the point of suspension. Its motion is kept up by means of the escapement, which is so constructed as to give it a slight push at each vibration. The ends of the two hooks have inclined surfaces against which each tooth of the wheel, as it leaves them, presses with considerable force, so as to throw the escapement forward a little the moment the tooth is set free. The impulse thus given is communicated, through the axis *o*, and the arm *a b*, to the pendulum.

83. *The Use of the Pendulum for measuring the Force of Gravity.* — We have seen that the rate of the vibration of pendulums of the same length depends on the force of gravity. If we represent by *g* the velocity that a body falling from a state of rest would acquire during a second, and by *l* the length of a pendulum beating seconds, then *g* will be equal to the length of the pendulum multiplied by the square of the number 3.1416. To find *g*, we have only to measure the length of a pendulum beating seconds, and then to multiply this length by the square of the number 3.1416.

Now it has been found that a pendulum beating seconds at London must be 39.13929 inches long. From this we get $g=386$ inches. One half of 386 inches is 193 inches, or 16 feet, 1 inch. This is the distance which a body will fall from a state of rest in a second.

SUMMARY.

A *pendulum* is a heavy body hung from a fixed point by means of a cord or rod. (75.)

The laws of the vibration of the pendulum are best investigated by means of a *simple pendulum*. (76.)

These laws are four in number.

1st. *When the length of the pendulum remains the same, and the amplitude of the vibrations does not exceed 3°, the pendulum always vibrates in the same time.* (77.)

2d. *For pendulums of the same length, the time of the vibrations is the same, whatever the pendulum may be made of.* (78.)

3d. *For pendulums of different lengths, at the same place, the time of the vibrations is proportional to the square root of the lengths.* (79.)

4th. *In different parts of the earth, the time of the vibrations for pendulums of the same length, is in the inverse ratio of the square root of the intensity of gravity.* (80.)

The pendulum in ordinary use is a *compound pendulum.* (81.)

The pendulum is used for measuring time. (82.)

It is also used for measuring the force of gravity. (83.)

PROBLEMS.

95. If a pendulum beating seconds at Paris is .99394 of a metre long, what would be the length of one beating half-seconds? Of one vibrating in two seconds?

96. If a pendulum at Paris one metre long vibrates in 1.00304 seconds, what will be the time of vibration for a pendulum 9 metres long? What for one 25 metres long? What for one $\frac{1}{4}$ of a metre long? What for one $2\frac{1}{4}$ metres long?

III.

MACHINES AND SOURCES OF MECHANICAL POWER.

THE LEVER.

84. When a workman wishes to raise a large stone, he places an iron bar under it, as in Figure 50, with a block under the bar near the stone, and then presses down upon the other end of the bar; or else he places the end of the bar under the stone, as in Figure 51, so that one end of it rests upon the ground, and then lifts upon the other end. The iron bar thus used constitutes one of the *simple machines*. It is called the *lever*. The stone to be raised is called the *weight*. The moving force applied at the other end of the bar is called the *power*; and the point on which the bar rests is called the *fulcrum*. The parts between the fulcrum and the points where the power and weight act are the *arms* of the lever. In the first case, the fulcrum was between the weight and the power; in the second case, the weight was between the fulcrum and the power. In the fishing rod (Figure 52) one hand is the fulcrum, the other hand, *P*, is the power, and the fish is the weight. Here the power is applied between the fulcrum and the weight.

Fig. 50.

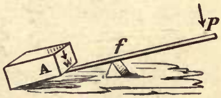


Fig. 51.

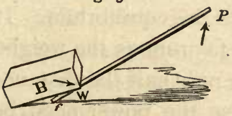
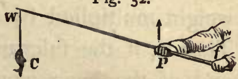


Fig. 52.



85. *Three kinds of Lever.* — We see from the above that there are three kinds of lever: —

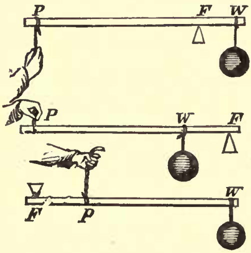
(1.) That with the fulcrum between the weight and power.

(2.) That with the weight between the fulcrum and power.

(3.) That with the power between the fulcrum and the weight.

These three kinds of lever are shown in Figure 53.

Fig. 53.



86. *The Law of the Lever.* — In the lever of the first kind, if the fulcrum is just half way between the weight and power, then on moving the lever a little the weight and power will move through equal distances. In this case it is found that the weight and power must be equal in order to balance each other, or to be in equilibrium. If the power were twice as far from the fulcrum as the weight, then the weight would move through only half the distance that the power does, and in this case the power need be only half the weight in order to balance it.

Thus we see that, in the case of the lever, the weight and power will balance each other when the power, multiplied by the distance through which it moves, equals the weight multiplied by the distance through which it moves. That is, if the fulcrum of a lever were so placed that one end of the lever would move through a thousand inches while the other end moved through one inch, then a power of one pound on the former would balance a weight of one thousand pounds on the latter.

87. *The Law of Machines in General.*—The same is found to be true in the case of every machine, however complicated; namely, that the power and weight will balance each other when, on setting the machine in motion, the power multiplied by the distance through which it moves equals the weight multiplied by the distance through which it moves.

There is no real gain of mechanical force in a lever or a machine of any kind. A machine is only an arrangement by which a small force acting through a great distance is converted into a great force acting through a small distance, or else a great force acting through a small distance is converted into a small force acting through a great distance.

When a small force, by acting through a great distance, is made to raise a great weight, or do a great deal of work, there is said to be a gain of power in the machine. When on the contrary a great force, in moving through a small distance, lifts only a small weight, or does very little work, there is said to be a loss of power in the machine. But whenever there is a gain in power there is a corresponding loss in speed, and whenever there is a loss in power there is a corresponding gain in speed. For if in the machine a power of one pound is made to move a weight of ten pounds, then the weight moves only one tenth as fast as the power. But when a power of ten pounds is made to move a weight of one pound, then the weight moves ten times as fast as the power.

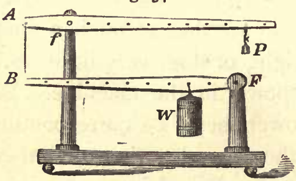
88. *Gain and Loss of Power in the Lever.*—In a lever of the first kind, when the fulcrum is just half way between the weight and power, there is neither gain nor loss in power. If the fulcrum is nearer the weight than the power, then there will be a gain in power and a loss in speed. If the fulcrum is nearer the power than the weight, there is loss in power and gain in speed.

In a lever of the second kind, the power is always farther from the fulcrum than the weight, and consequently it always moves through greater distance. Hence in this kind of lever there is always a gain in power and a loss in speed.

In a lever of the third kind, the weight is always farther from the fulcrum than the power, and consequently the weight always moves through the greater distance. There is therefore in this kind of lever always a loss in power and a gain in speed.

89. *The Compound Lever.*—Sometimes two or more simple levers are combined, as shown in Figure 54. Suppose that *P* be five times as far from the fulcrum *f* as *A* is, the point *P* will then move five times as fast as the point *A*, and a pull of one pound on *P* will exert a pull of five pounds on *A*. If *B* is five times as far from the fulcrum *F* as *W* is, the five pounds of pull on *B* will exert twenty-five pounds of pull at *W*. In this case, one pound of pull exerted at *P* will balance twenty-five pounds at *W*. But it would be found on trial that on pulling *P* down one inch, *W* would be raised only one twenty-fifth of an inch.

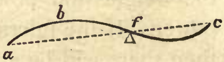
Fig. 54.



Such a combination of levers is called a *compound lever.*

90. *Bent Levers.*—Sometimes the arms of the lever are bent, as shown in Figure 55. In such a lever the lengths of the arms are straight lines drawn from the fulcrum at right angles to the lines which show the direction in which the power and weight act.

Fig. 55.



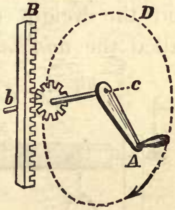
The common claw-hammer, as used for drawing nails, is an illustration of this kind of lever.

THE WHEEL AND AXLE.

91. When a weight is raised by means of the lever, it can be raised but a short distance at a time. After raising the weight a little way it must be propped up, and the lever must be readjusted. On this account the lever cannot be conveniently used when a weight is to be raised a considerable distance.

92. *The Rack and Pinion.*—In Figure 56 we have a machine called the *rack and pinion.* It consists of the *crank A*, which can be made to turn a small toothed wheel called the *pinion.* On turning the pinion, its teeth one after another catch under the teeth of an upright bar *B*, and each tooth raises the bar a little. This upright bar is called the *rack.* On turning the crank, then, the rack rises without interruption; and if the rack is placed under the weight, it will carry up the weight as it rises. As the weight can thus be raised the length of the rack without interruption, the rack and pinion is much more convenient than the simple lever, when the weight is to be raised a considerable distance.

Fig. 56.

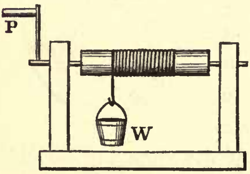


93. *The Rack and Pinion is a Modification of the Lever, in which the Pinion takes the Place of the short Arm.*—In the rack and pinion, the crank takes the place of the *long arm* of the lever; the rod or *axle* upon which the pinion turns takes the place of the *fulcrum;* and the pinion takes the place of the *short arm.* Each tooth of the pinion is in fact the short arm of a lever of which the crank is the long arm, and the pinion is a contrivance by which the lever is furnished with several short arms instead of one. The advantage of multiplying the

short arm in this way is this: when a short arm has raised the weight as far as it can, it is not necessary to prop up the weight and readjust the lever, for the next short arm then comes in play and raises the weight farther, and so on.

94. *The Windlass.* — Another way to multiply the short arms of a lever would be to fill up the space between the teeth of the pinion so that it may become a *barrel*, and then fasten the weight to one end of a rope, the other end of which is fastened to this barrel. On turning the crank the rope would be wound upon the barrel and the weight raised. The machine just described is called the *windlass*, and is shown in Figure 57.

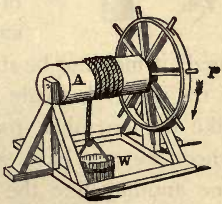
Fig. 57.



In the windlass, the length of the short arm is the distance from the circumference, or outside, of the barrel to its centre. This distance is called the *radius* of the barrel, and in the barrel there are as many short arms as there are *radii*. The length of the long arm of the lever is the length of the crank. If the crank were ten times as long as the radius of the barrel, a power of one pound at the end of the crank would exert a force of ten pounds at the circumference of the barrel. On turning the crank round once, it is evident that the end of the crank would move through a path like that shown by the dotted line in Figure 56, and that this path would be ten times as long as the circumference of the barrel. On turning the crank once round, the rope would be wound round the barrel once, and the weight would be raised a distance equal to the circumference of the barrel. In this case, then, the power would move through ten times the distance the weight moves through in the same time, and, according to the law of machines (87), a power of one pound at the end of the crank ought to balance ten pounds of weight at the circumference of the barrel.

95. *The Capstan.* — In the windlass, the longer the crank and the smaller the barrel, the greater the gain of power. If, however, the barrel is made too small, it is not strong enough to support the weight; while if the crank is made too long, it cannot be conveniently turned with the hand. But the crank, or long arm of the lever, may be multiplied in the same way as the short arm was multiplied in the case of the pinion and the barrel. Thus in the windlass, just described, instead of one crank there may be a number of spokes, and a man by standing at one side may pull upon one spoke after another as they come within his reach, and thus turn the barrel, though he could not reach far enough to turn round a single spoke, if it were arranged like a crank. If the barrel were placed upright, a man or several men might walk round it, pushing against the spokes. A windlass arranged in this way is called a *capstan*, and is much used on board ships.

Fig. 58.



96. *The Wheel and Axle.* — If the spokes are connected so as to form a wheel, as shown in Figure 58, the barrel is called the *axle*, and the machine is called the *wheel and axle.*

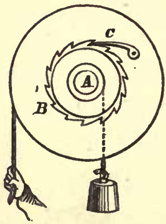
In the wheel and axle, the radius of the wheel is the long arm of a lever, and the radius of the axle is the short arm. Therefore, the larger the wheel and the smaller the axle, the greater the weight which a power of one pound applied to the circumference of the wheel will balance on the axle.

Power may be applied to the wheel, either by means of pegs projecting from its rim, as in Figure 58, or by a rope or band passing around it, as in Figure 59.

The law of machines (87) may be readily illustrated by means of the wheel and axle. Suppose that a rope passes over the wheel and another over the axle, and that the radius of the wheel is eight times as long as that of the axle. On hanging a weight of one pound to the rope from the wheel, it will be found that a weight of eight pounds must be hung to the rope from the axle in order to balance it; and it will be found, on turning the wheel, that the weight hung from the wheel moves through eight inches, while that hung from the axle moves through one.

97. *The Ratchet.* — The *ratchet* is an arrangement to keep the wheel from turning except in one direction. It consists of a catch *c* (Figure 59), which plays into the teeth of the wheel *A B*. It thus allows the wheel to turn to the left, but keeps the weight from pulling it back towards the right.

Fig. 59.

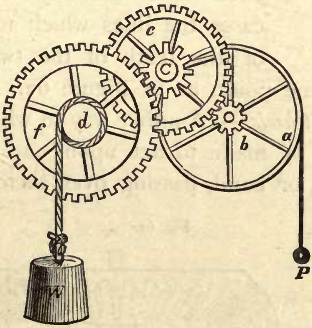


98. *Wheel-work.* — In the wheel and axle, the larger the wheel and the smaller the axle, the greater the gain of power. But, as has already been said (95), if the barrel is made very small, it may not be strong enough; and on the other hand, if the wheel is made very large, it will be too heavy and take up too much room. Instead of using such a large wheel, we may have several wheels and axles acting upon one another, like the levers in the compound lever (89). Such a combination, or *train*, of wheels and axles is often called *wheel-work*. The power is applied to the circumference of the first wheel, the axle of which acts upon the circumference of the second wheel, which in turn, by means of its axle, acts upon the circumference of the third wheel, and so on; the weight being hung to the axle of the last wheel.

99. *Cog Wheels.* — There are various ways in which the axle of one wheel is made to act on the circumference of another. Sometimes the one turns the other by rubbing against it, or by *friction.* The most common way, however, is by means of *teeth* or *cogs* raised on the surfaces of the wheels and axles. The cogs on the wheel are usually called *teeth,* while those on the axle are called *leaves,* and the part of the axle from which they project is called the *pinion,* as in the rack and pinion already described (92).

A train of wheels thus arranged is shown in Figure 60.

Fig. 60.

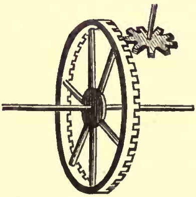


100. *The gain of power by Wheel-work.*—In the train of wheels in Figure 60, if the circumference of the wheel *a* is 36 inches, and that of the pinion *b* is 9 inches, or one fourth as great, a power of one pound at *P* will exert a force of four pounds on *b*. If the circumference of the wheel *e* be 30 inches, and that of the pinion *C* 10 inches, the four pounds acting on the former will exert a force of twelve pounds on the latter. If the circumference of the wheel *f* be 40 inches, and that of the axle *d* 8 inches, the twelve pounds acting on *f* will exert a force of sixty pounds on *d*. One pound at *P* will then balance sixty pounds at *W.*

But in this case, as in that of the windlass (94), it will be seen that what is gained in power is lost in speed; since the one pound at P must move through sixty inches in order to raise the sixty pounds at W one inch.

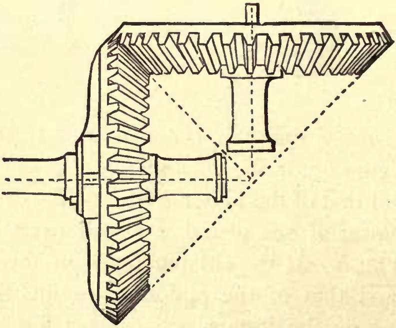
Cog-wheels which have their teeth arranged as in Figure 60 are called *spur-wheels.* If the teeth project from the *side* of the wheel, as in Figure 61, it is called a *crown-wheel.* If their edges are sloped, as in Figure 62, the wheel is called a *bevel-wheel.* Bevel-wheels may be inclined to each other at any angle. In all cases the lines which mark the slope of the teeth of the two wheels will meet at the same point, as in Figure 62.

Fig. 61.



101. *Belted Wheels.* — Another way in which the wheels and axles may be made to act upon one another is by means of a *belt*, or band, passing over them both. They

Fig. 62.

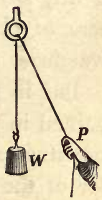


may thus be at any distance apart, and may turn either the same way or contrary ways, according as the belt does or does not *cross* between them. A cog-wheel and its pinion must, of course, always turn in contrary directions.

THE PULLEY.

102. In Figure 63 *H* is a fixed ring. Through this a cord passes, to which the weight *W* is hung. By pulling *down* the cord at *P*, the weight is drawn *up*. It is often desirable thus to *change the direction* of the power.

Fig. 63.

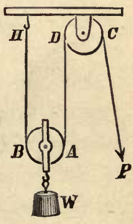


If we use a ring for this purpose, much of the power will be wasted by the *friction*, or rubbing, of the rope against the ring. We may get rid of a good deal of this friction by using, instead of the ring, a wheel with a groove around it for keeping the cord in place. Such a wheel is called a *pulley*.

There would be no gain in power by the use of the pulley. It is evident that one pound on one side of the wheel would balance just one pound on the other side; and that if the former were drawn down one inch, the latter would be drawn up just one inch.

103. *Fixed and Movable Pulleys.* — In Figure 64, the frame of the pulley *D C* is fastened to the ceiling; the frame of the pulley *A B* rises as the rope *P* is drawn down. A pulley like *D C* is called a *fixed* pulley; one like *AB*, a *movable* pulley. The frame of the pulley is often called the *block*.

Fig. 64.



104. *The Law of the Pulley.* — In the combination, or *system*, of pulleys in Figure 64, it is evident that the rope must have the same *tension*, that is, must have the same strain upon it, from one end to the other. This fact, namely, that *a cord when stretched must have the same strain upon it throughout its length*, is called the *law* of the pulley.

105. *Systems of Pulleys with one Rope.* — In Figure 64.

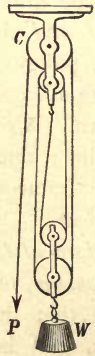
the tension or strain of the rope is equal to the power *P*, since it balances the power. If a weight of one pound is hung to the rope at *P*, there will be a strain of one pound on the part of the rope on that side of the pulley. There must then be a strain of one pound upon the part of the rope between *A* and *D*, and a strain of one pound between *B* and *H*. These two tensions, *A D* and *B H*, will evidently sustain a weight of two pounds at *W*. In this system of pulleys, then, a power of one pound balances a weight of two pounds.

But in this case, as in every other of the kind, what is gained in power is lost in speed. If the power *P* is drawn down one foot, the weight *W* will rise only half a foot; for of the one foot added to the length of *C P*, one half will be taken from *A D* and one half from *B H*.

In the system of pulleys shown in Figure 65, we see that one pound at *P* will balance three pounds at *W*, since each

Fig. 65.

Fig. 66.



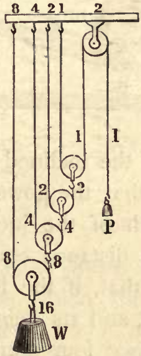
of the three parts of the rope on that side of the pulley *C* has a tension of one pound. But *P* must be drawn down three feet in order to raise *W* one foot.

In Figure 66, we have a system of pulleys in which the weight is four times the power; and in this case the power evidently moves four times as far as the weight.

106. *Systems of Pulleys with more than one Rope.* — Figure 67 represents a system of pulleys, in which two ropes are used. Here a weight of four pounds is balanced by a power of one pound. The parts of the rope *A D* and *A B* must each have a tension equal to the power. The rope *A C B* balances the two tensions, *B P* and *B A*, and must therefore have a tension of twice the power. The three

Fig. 67.

Fig. 68



tensions supporting the pulley *A* amount therefore to four times the power.

In the system shown in Figure 68, four ropes are used. The tensions of the several ropes will be readily understood from the numbers. It will be seen that in this case the power is doubled by each movable pulley which is added; but, as in all the systems we have examined, what is gained in power is lost in speed.

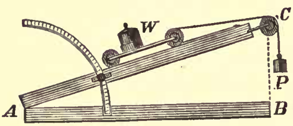
THE INCLINED PLANE.

107. When a heavy cask is to be raised into a cart or dray, a ladder is often used. One end of the ladder is

placed upon the cart behind and the other end upon the ground, and the cask is rolled up the inclined surface thus formed. In this way one man is able to raise a load of several hundred weight with comparative ease. An inclined surface used in this way is called an *inclined plane.*

We have examples of the inclined plane on a large scale in *roads.*

Fig. 69.

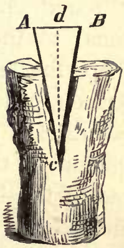


108. *The Law of the Inclined Plane the same as that of other Machines.* — In Figure 69 we have an inclined plane. *W* is the weight, which is balanced by the power *P.* *B C* is the *height* of the inclined plane, and *A C* is its *length.* It is evident that the power must descend a distance equal to the length of the inclined plane, in order to raise the weight a distance equal to its height. Now it is found on trial that, if the length of the inclined plane is sixteen feet, and its height four feet, a power of one pound will balance four pounds of weight. But one multiplied by sixteen equals four multiplied by four. That is, the power multiplied by the distance through which it acts equals the weight multiplied by the distance through which it is raised. It follows from the above, that the greater the length of the inclined plane, compared with its height, the less the force necessary to raise a weight, and the slower the weight rises.

THE WEDGE.

109. Instead of lifting a weight by moving it along an inclined plane, we may do the same thing by pushing the inclined plane under the weight. When used in this way the inclined plane is called the *wedge.* A

Fig. 70.



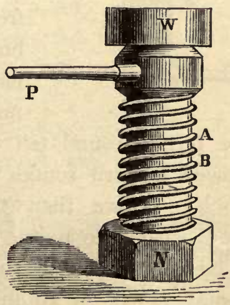
wedge which is used for splitting wood has usually the form of a double inclined plane, as in Figure 70. The law of the wedge is the same as that of the inclined plane, but since a wedge is usually driven by a blow instead of a force acting continuously, it is difficult to illustrate this law by experiments.

110. *Uses of the Wedge.* — The wedge is especially useful when a large weight is to be raised though a very short distance. Thus a tall chimney, the foundation of which has settled on one side, has been made upright again by driving wedges under that side. So, too, ships are often raised in docks by driving wedges under their keels. Cutting and piercing instruments, such as razors, knives, chisels, awls, pins, needles, and the like, are different forms of wedges.

THE SCREW.

111. In Figure 71 we have a machine called the *screw.* It is a movable inclined plane, in which the inclined surface winds round a cylinder. The cylinder is the *body* of the screw, and the inclined surface is its *thread.*

Fig. 71.

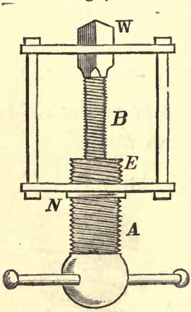


The screw usually turns in a block *N*, called the *nut.* Within the nut there are threads exactly corresponding to those on the screw. The threads of the screw move in the spaces between those of the nut.

The power is usually applied to the screw by means of a lever *P*. Sometimes the screw is fixed and the nut is movable, and sometimes the nut is fixed and the screw movable.

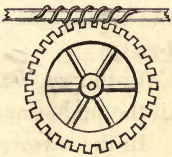
112. *Hunter's Screw.*—In Figure 71, if we turn the lever *P* round once, the weight *W* will be raised a distance equal to the space between two threads of the screw. Were the lever of such a length that its end would describe a path 10 feet long, and were the distance between two threads of the screw $\frac{1}{4}$ of an inch, and were there no friction in the nut, a power of one pound applied to the end of the lever would exert a force of 480 pounds upon the weight. It will be seen from this that the mechanical advantage of the screw may be increased by increasing the length of the lever by which it is turned, or by bringing the threads closer together. But, if the threads are brought too near together, they become too weak; while, on the other hand, the machine becomes unwieldy if the lever is made too long. These objections have been obviated in the *differential* screw, contrived by Hunter, and shown in Figure 72. *N* is the nut in which the screw *A* plays. We will suppose that the threads of this screw are $\frac{1}{10}$ of an inch apart. This screw *A* is a hollow nut, which receives the smaller screw *B*, the threads of which we will suppose to be $\frac{1}{11}$ of an inch apart. This small screw is free to move upward and downward, but is kept from turning round by means of the frame-work. If by means of the handle the larger screw be turned round ten times, and the smaller screw be allowed to turn round with it, the point *W* will rise an inch. If we then turn the smaller screw ten times backward, the point *W* will move down $\frac{10}{11}$ of an inch. The effect of both these motions will be to raise the point *W* $\frac{1}{11}$ of an inch. But if the smaller screw has been turned upward ten times and then downward ten

Fig. 72.



times, the effect is the same as if it had been kept from turning. Hence on turning the lever round ten times, the point W will be raised $\frac{1}{11}$ of an inch, or the *difference* of the distances between the threads in the two screws, while the point E has been raised an inch. According to the law of machines, then, the pressure at W is eleven times as great as at E.

Fig. 73.



113. *The Endless Screw.* — In Figure 73, the thread of the screw works between the teeth of the wheel. Hence on turning the screw the wheel must turn. Since as fast as the teeth at the left escape from the screw those on the right come up to it, the screw is acting upon the wheel continually. Hence this machine is called the *endless screw.*

SUMMARY.

A *machine* is a contrivance by which force is made to do work. (84.)

In a machine there is no real gain of force, but a force may be changed in direction, and a small force acting through a great distance may be converted into a large force acting through a small distance, or a large force acting through a small distance may be converted into a small force acting through a great distance. (87.)

The first simple machine is the *lever*. (84.)

There are *three kinds* of levers, depending upon the relative position of the *weight*, the *fulcrum*, and the *power*. (85.)

In a lever of any kind the weight and power will balance each other when the weight multiplied by the distance through which it moves is equal to the power multiplied by the distance through which it moves. (86.)

It is the law of every machine that the power and weight will balance each other when the power multiplied by the distance through which it moves is equal to the weight multiplied by the distance through which it moves in the same time. (87.)

A *compound lever* is a machine in which two or more simple levers are combined. (89.)

The *rack and pinion* is a lever whose long arm appears in the crank, and whose short arm is multiplied in the pinion. (92.)

In the *windlass*, the barrel and the rope take the place of the pinion and the rack. (93.)

In the *wheel and axle*, the long arm of the lever is multiplied as well as the short one. (96.)

When the axle is upright the wheel and axle is called a *capstan*. (95.)

Several wheels are often combined so as to act upon one another. (98.)

The wheels may be made to act upon one another by means of *cogs*, or by means of *belts*. (99, 101.)

The direction in which a force acts may be changed by means of a single fixed *pulley*. (102.)

In a system of pulleys, the mechanical advantage depends upon the fact that *a stretched rope will have the same tension throughout its whole length.* (104.)

A system of pulleys may be arranged with one rope, or with several ropes. (105, 106.)

The fourth simple machine is the *inclined plane*. (107.)

The fifth simple machine is the *wedge*. This is really a movable inclined plane which is pushed under the weight to be raised. (109.)

The sixth simple machine is the *screw*. This is also a movable inclined plane arranged round a cylinder.

Hunter's differential screw and the *endless screw* are important modifications of this simple machine. (111 – 113.)

PROBLEMS.

97. In a lever the short arm is 5 decimetres long, and the long arm 61 decimetres long. How far will the end of the long arm move while the end of the short arm moves through 3 centimetres?

98. How far will the end of the short arm move while the end of the long arm is moving through 30 centimetres?

99. In a lever the short arm is 2 metres long, and the long one 50 decimetres long. A power of 2 kilogrammes is applied to the end of the long arm. What weight at the end of the short arm will it balance?

100. While the weight in the last example is moving through 3 decimetres, how far will the power move?

101. A weight of 60 decagrammes is applied at the end of the long arm of the lever in the above example. What power must be applied at the end of the short arm to balance it?

102. In a rack and pinion the radius of the pinion is 10 decimetres. What must be the length of the crank in order that a power of 8 grammes may balance 300 grammes of weight?

103. In a wheel and axle the circumference of the wheel is 6 metres and that of the axle 30 centimetres. What weight will a power of 3 grammes balance?

104. In a train of wheels a power of 1 gramme balances a weight of 43 kilogrammes. What distance must the power move through while the weight moves through 50 decimetres?

105. In a system of pulleys a power of 1 gramme balances a weight of 245 kilogrammes. How far will the weight move while the power is moving through 1 metre?

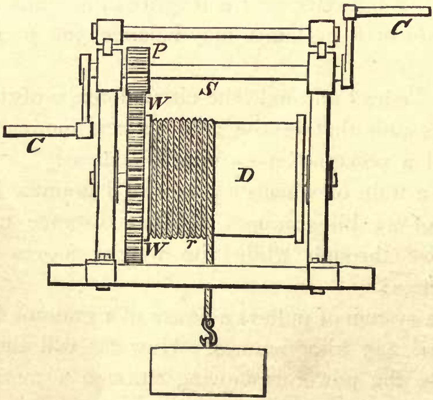
HAND POWER.

114. We have now seen how forces may be transformed, so that a small force acting through a long distance shall be equivalent to a great force acting through a short distance, or a great force acting through a short distance shall be equal to a small force acting through a great distance. We next inquire what are the *sources* of mechanical power.

115. *Hand Machines.*—One of the most familiar sources of mechanical power is the human hand. Machines by which this power is applied to doing work are called *hand machines.* An iron crow-bar is one of the simplest hand machines. It is, as we have seen (84), a lever of the first or second kind, according to the way in which it is used.

The ordinary windlass and the capstan are examples of hand machines of the wheel and axle kind; while the tackle which is so often used for hoisting weights is an example of a hand machine of the pulley kind.

Fig. 74.



116. *The Crab.*—The *crab,* shown in Figure 74, is

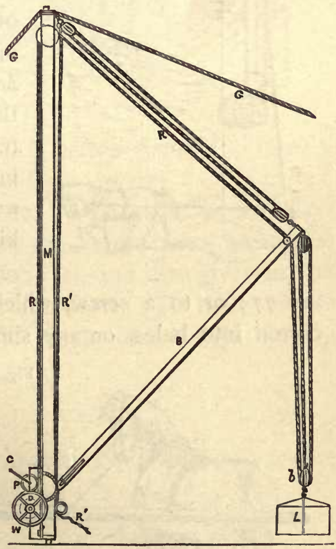
hand machine of the wheel and axle class. It consists of a pinion *P* turned by two cranks *C* and *C*, and acting upon the toothed wheel *W*. To the axis of this wheel is fixed the barrel *D*, to which the weight is hung by the rope *r*.

The gain of power in this machine can be computed by the principles already explained. (94, 98.)

The crab is much used for setting stone in the building of houses, and for other work of the same kind.

117. *The Derrick.* — The *derrick* (Figure 75) consists of a mast *M*, which is kept upright by means of ropes, or *guys*, *G*, *G*, fastened to posts driven into the earth. *B* is an arm, or *boom*, attached to the mast by a hinge, and kept in any required position by means of the rope *R'*. The mast and boom serve as the supports of a system of pulleys, worked by a *crab* at the foot of the mast. *L* is the load, or weight to be raised.

Fig. 75.

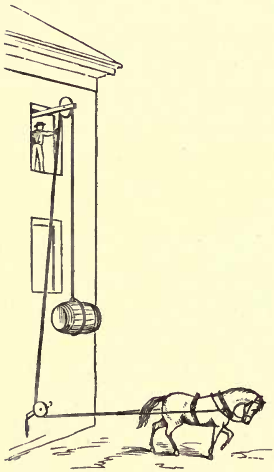


The system of pulleys in the derrick represented here is precisely like that shown in Figure 65, and the mechanical advantage from its use will be the same as there explained; and this, multiplied by the mechanical advantage obtained by means of the crab, will give the whole gain of power in the machine.

HORSE POWER.

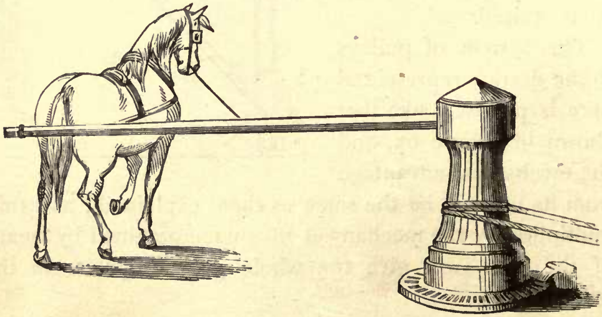
118. The strength of horses is employed in drawing loads over our roads, which, as we have seen, are in many cases inclined planes. Horses are often used in raising weights by means of pulleys, as shown in Figure 76.

Fig. 76.



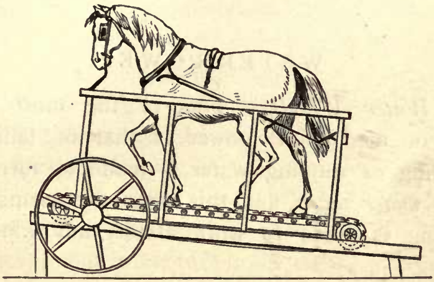
119. *Horse Powers.* — Machines by which the strength of horses is applied to the doing of work are usually called *horse powers*. In some of these the horse walks round a circle, turning an upright shaft, which may give motion to a *train of wheels* (98) for driving various kinds of machinery; or to a *capstan* (95), as shown in Figure 77; or to a screw, which may be used for pressing cotton into bales, or any similar work.

Fig. 77.



In another class of horse powers, the horse is placed on the surface of a large horizontal wheel, or on a movable platform. In this case it is the road, and not the horse, that travels. One form of this kind of horse power is shown in Figure 78. It consists of a platform made of wooden

Fig. 78.



bars fastened to a chain, which passes round two wheels. The horse is put upon this *endless platform*, as it is called, and is harnessed to the frame of the machine, as represented in the Figure. When the horse draws, he pushes the platform backward with his feet, and thus gives motion to the wheels round which it passes. To these wheels machinery may be connected in any of the ways already described.

WIND POWER.

120. We have a familiar example of the wind as a source of mechanical power in the sailing of ships.

These are rigged so as to present to the wind a large extent of canvas, called *sails*. The wind blowing against these urges the ship forward.

Sometimes sails, or broad vanes of wood, are arranged

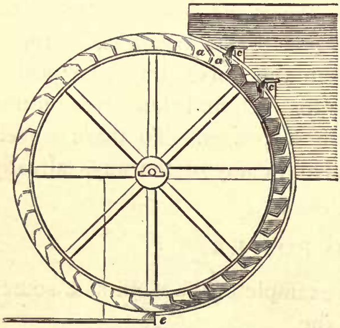
Fig. 79.

on the arms of a wheel which is mounted in a high tower. The wind blowing against these arms causes the wheel to rotate, and by means of wheel-work this is made to carry other machinery. Such an arrangement is called a *wind-mill*, and is shown in Figure 79.

WATER POWER.

121. *Water Wheels.* — One of the most important sources of mechanical power is that of falling water. The falling or running water is made to turn a wheel, called a *water wheel*, and this wheel by means of bands or gearing is made to work almost any kind of machinery.

Fig. 80.



Water wheels are of various forms. Some turn on an upright axis, and others on a horizontal axis. The latter are called *vertical water wheels* and the former *horizontal water wheels.*

122. *Vertical Water Wheels.* — One of the most common forms of vertical water wheels is represented in Figure 80. It consists of a series of boxes, or *buckets*, arranged on the outside of a wheel or cylinder. Water is allowed to flow into these buckets on one side of the wheel, and by its weight causes the wheel to turn. The buckets are so constructed that they hold the water as long as possible while they are going down, but allow it all to run out before they begin to rise on the other side.

A wheel like this is called a *breast-wheel.*

The *overshot* wheel is similar to the breast-wheel in all respects, except that the water is led over the top of the wheel and poured into the buckets on the other side.

The *undershot* wheel has boards projecting from its circumference, like the paddle-wheel of a steamboat. The water runs under the wheel, and turns it by the force of the current pressing against the boards.

123. *Barker's Mill.* — In Figure 81 we have a hollow upright cylinder, with two horizontal arms at the bottom, and turning on an axis. The cylinder is open at the top, but closed below, except that it has two holes on opposite sides of the arms near the end, as shown in the Figure. If water be poured in at the top, the cylinder begins to turn round, and will continue to turn as long as the supply of water is kept up. If the holes in the arms are stopped up, the cylinder ceases to move. This apparatus is known as *Barker's mill.* Its action is easily understood when we recollect that liquids press equally in all directions (17). If the holes in the arms are plugged up, the water presses forward against the plug; and it presses backward against the opposite part of the arm with an equal force. These two equal forces acting in opposite directions would just balance each other, so that there would be no motion. If now we remove the plug, there will be no pressure against that part of the arm to balance the backward pressure against the opposite side; and the arm consequently turns backward. As the openings in the two arms are on opposite sides of the tube, the backward pressure on each arm tends to turn the cylinder round in the same direction.

Fig. 81.

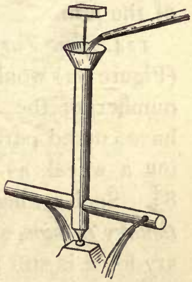
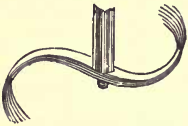


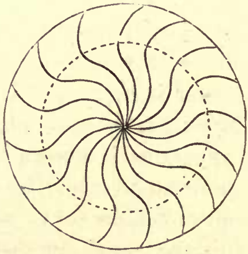
Fig. 82.



This machine is found to gain in power by bending round the arms, as shown in Figure 82; for the water is thus made to press more powerfully against the bend of the arm as it flows through the tube. It will be noticed that there are two forces which tend to turn the wheel in this case; (1) the reaction proper, caused by the removal of the pressure at the opening at the end; and (2) the angular force of the current as it strikes against the bend of the arm.

124. *The Turbine Wheel.* — The power of Barker's mill (Figure 82) would evidently be increased by increasing the number of the arms. Instead of these arms we might have curved partitions placed between two flat discs, forming a wheel, as shown in Figure 83. Such a wheel is called a *reactionary turbine*, since the reactionary force is still predominant.

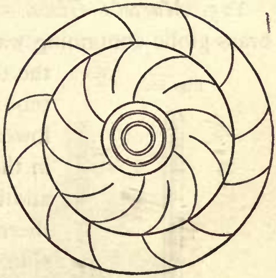
Fig. 83.



Suppose now that the discs and partitions were cut round where the dotted circle is seen in the figure, and that the outer part were supported in some way beneath, so that it might turn round freely while the central parts of the wheel were kept stationary. If water were poured into the wheel from above, the outer part would, of course, turn round just as the whole wheel did before it was cut in two. For the action of the water against the partitions would evidently be the same as before, and it was this action of the water which turned the wheel. And there would be this advantage in the use of the divided wheel, that the outer part, while turning, would not have to carry the weight of the whole column of water, as the wheel did before it was divided.

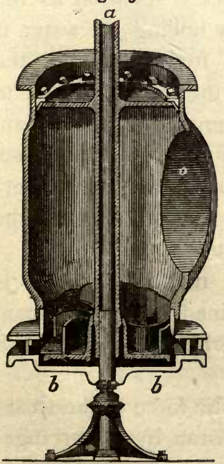
Again, by turning the inner set of partitions as shown in Figure 84, the current is made to strike the outer partition in such a direction as to make its angular force the greatest possible. A wheel thus arranged is the ordinary *turbine*, and in it the angular force of the escaping current is the chief motive power. It is the most efficient water-wheel ever constructed.

Fig. 84.



A section of one form of this wheel is shown in Figure 85. The wheel *b b* corresponds to the outer part of the wheel in Figure 83. It is supported from below and turns on an axis, as represented. Within this wheel are stationary partitions curved, as shown in Figure 84. These partitions are placed at the bottom of a large cylinder, into which the water is brought by the pipe *o*. The water flows between the fixed partitions against the partitions of the wheel *b b*, causing it to turn round rapidly. The water is then discharged at the circumference of the wheel *b b*.

Fig. 85.

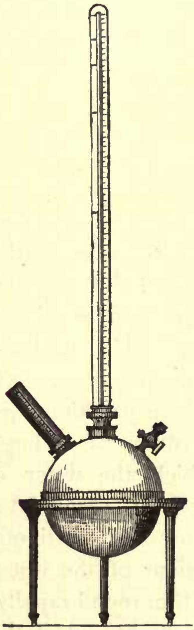


There are many kinds of turbines, and their effective power is from 75 to 88 per cent of that in the acting body of water. In the best forms of overshot and breast wheels it is from 65 to 75 per cent, and in undershot wheels from 25 to 33 per cent.

STEAM POWER.

125. *Marcet's Globe.* — In Figure 86 we have a stout brass globe containing water, and serving as a boiler. Into the top is fastened a glass manometer tube (48) about three feet long, whose lower end dips under mercury placed in the bottom of the globe. Through another opening passes the tube of a thermometer, the bulb of which is inside the globe.

Fig. 86.



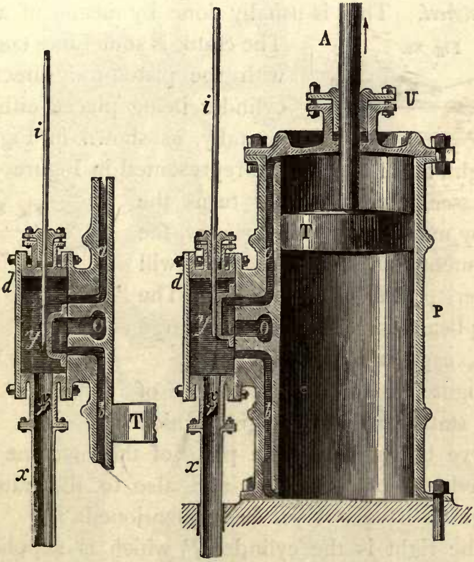
Open the stopcock seen on the right of the globe, boil the water for some time to expel the air, and then close the stopcock. As soon as the steam formed by boiling the water is thus prevented from escaping, the temperature of the globe begins to rise. At the same time, the expansive force of the steam will increase, raising the mercury in the manometer; and the hotter the globe gets, the higher the mercury rises.

We see, then, that when steam is formed in a confined space, its expansive force, or *elasticity*, increases with the temperature.

126. *The Steam Engine.* — The elastic force of the steam thus formed can be made to work a piston by the arrangement shown in Figure 87.

The steam coming from the boiler by the tube *x* passes into the box *d*. From this box extend two pipes, *a* and *b*, for carrying the steam, one above and the other below, the piston. A sliding valve *y* is so arranged that it always closes one of these pipes. In the right-hand Figure the lower pipe *b* is open, and the steam can pass in under the piston and force it up. At the same time the steam which has done its work on the other side of the piston passes out from the cylinder through the pipes *a* and *O*.

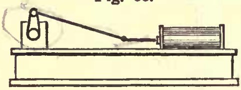
Fig. 87.



The sliding valve is connected by means of the rod *i* with the crank of the engine, so that it moves up and down as the piston moves down and up. As soon, then, as the piston has reached the top of the cylinder, the sliding valve is brought into the position shown in the left-hand Figure. The steam now passes into the cylinder above the piston through the pipe *a* and forces the piston down, and the steam on the other side which has done its work goes out through *b* and *O*. The sliding valve is now again in the position shown in the right-hand Figure, and the piston is driven up again as before ; and thus it keeps on moving up and down, or in and out. This kind of motion is called *reciprocating* motion.

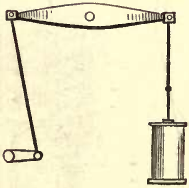
In using the engine for doing work, it is generally necessary to change this reciprocating motion into a *rotary* one ; that is, to make the piston, as it moves up and down, *turn a wheel.* This is usually done by means of a *crank.*

Fig. 88.



The crank is sometimes connected with the piston-rod directly, the cylinder being placed either horizontally, as shown in Figure 88, or upright, as in the engine represented in Figure 90. In other cases, the piston-rod turns the crank by means of a *walking-beam*, the arrangement and action of which will be understood from Figure 89. The walking-beam is much used for large engines, especially on steamboats.

Fig. 89.



In Figure 90 we have a picture of a small stationary steam-engine, which will serve to show how the parts of the machine already described are put together, and also to illustrate those parts which have not yet been mentioned.

On the right is the cylinder *P*, which is supplied with steam from the boiler by the pipe *x*. The waste steam is carried away by the pipe *L*. Within the cylinder is the piston moving up and down as explained above. The piston-rod *A* moves the crank *M*, and thus turns the axle *D*, which may be connected with the machinery to be driven, by means of a belt *X*, as here, or by a train of wheels, or in various other ways. *Q* is a pump, like that shown in Fig. 36, which supplies the boiler with water, through the pipe *R*. It is worked by the engine itself by means of the rod *g* and the *cam*, or *eccentric*, *E*.

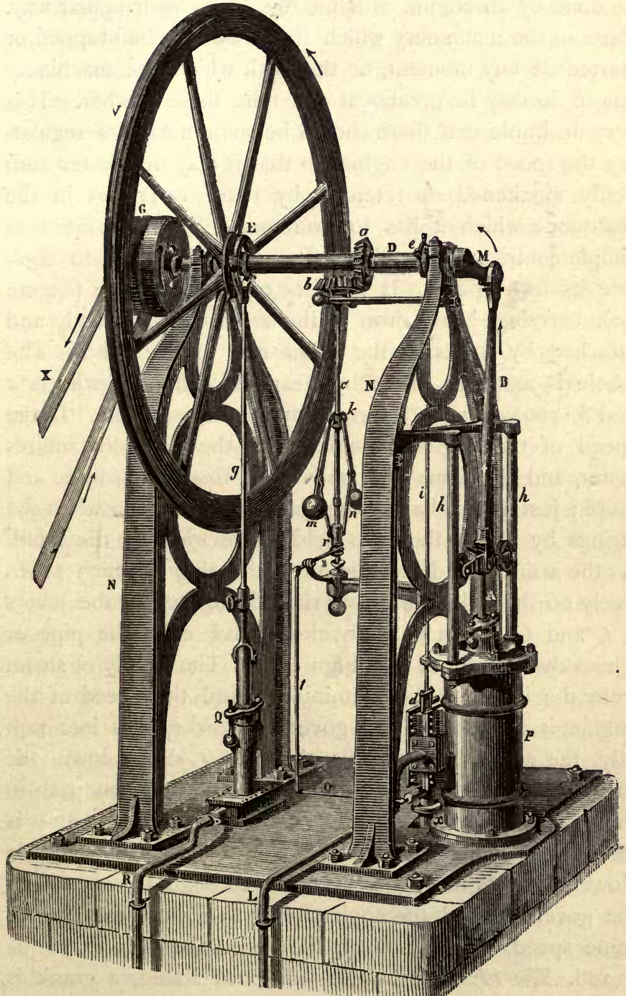


Fig. 90.

127. *The Governor.* — It often happens that the work to be done by an engine is liable to vary in an irregular way. Parts of the machinery which it drives may be stopped or started at any moment, or the work which the machinery has to do may be greater at one time than another. It is very desirable that there should be some means of regulating the speed of the engine, so that it may not be too suddenly quickened or retarded by these variations in the resistance which it has to overcome. The *governor* is a simple contrivance by which the engine is made to regulate its own speed. It consists of two arms, *k r* (Figure 90), carrying heavy iron balls, *m*, *n*, at one end, and attached by joints at the other end to the rod *c*. The whole is made to rotate by means of the bevel-wheels *a* and *b* (100), which are turned by the engine itself. If the speed of the engine is quickened, the governor rotates faster, and the arms and balls tend to separate more and more; just as two balls hung side by side will do when the strings by which they are held are twirled by the hand. As the arms spread out they raise the ring *r*, which slides freely on the rod *c*; and as *r* rises, it acts upon the levers *s*, *t*, and *O*, which partially close valve *a* in the pipe *x*. This valve is seen at *v* in Figure 87. The supply of steam from the boiler is thus diminished, and the speed of the engine is retarded. The governor now rotates less rapidly, the arms drop a little, the ring *r* slides down, the valve in *x* is opened a little more, letting steam pass to the cylinder more freely, and the speed of the engine is quickened again. Thus any tendency to go faster or slower corrects itself very promptly through the agency of the governor, and the engine runs at almost exactly the same speed, however much the resistance may vary.

128. *The Fly-Wheel.* — As has been stated, a crank is commonly used to change the *reciprocating* motion of the piston into a *rotary* one. But as the crank turns round, it

will be seen that there are two points where the piston-rod is pushing exactly in the direction of the point round which the crank moves; and that at these points it does not tend to turn the crank at all. There must therefore be some means of carrying the crank past these *dead points*, as they are called. This is the office of the *fly-wheel V*, a heavy iron wheel attached to the axle *D*. The great momentum of this heavy mass tends to carry the axle round with a uniform motion, notwithstanding the variations in the power acting upon it.

129. *High Pressure and Low Pressure Engines.* — When the steam after doing its work in the cylinder is carried into a cold chamber, the engine is said to be of *low pressure;* when it is forced out into the air, the engine is said to be of *high pressure.* In the former case, the steam is condensed into water in the cold chamber, and a vacuum is thus formed behind the piston. In the latter case, the piston has to act against the pressure of the atmosphere, which, as we have learned (38), is equivalent to a weight of 15 pounds on each square inch of its surface. It is evident that a greater pressure of steam will be necessary to move the piston in the latter case.

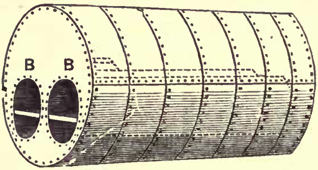
130. *The Boiler.* — In the boiler the steam is produced, and confined until it is used in moving the piston. It must therefore be capable of furnishing all the steam needed by the engine in any given time, and strong enough to resist the expansive force of the steam shut up within it.

Boilers are usually made of plates of wrought iron or copper riveted together. Copper is the best material, but iron is almost always used on account of its cheapness.

In order to get the full effect of the fire, the hot gas and smoke from it are usually made to pass through flues or tubes in the body of the boiler; and the water comes directly in contact with these flues or tubes. This is illustrated in the *Cornish boiler*, as it is called, shown in

Figure 91, and considered one of the best forms of boiler.

Fig. 91.



It is a cylinder, frequently more than forty feet long, and from five to seven feet in diameter, with two cylindrical flues, *B B*, extending its whole length. These flues serve as the furnace in which the fire is built. The hot gas and smoke after passing through the flues are made to circulate round the outside of the boiler before escaping into the chimney.

Another form of boiler is represented in Figures 92 and 93. This boiler is cylindrical, but instead of the flues of the Cornish boiler, it has two long cylindrical tubes, *B B*, connected with it by upright pipes. These tubes are exposed to the direct flame of the fire. The hot gases and smoke after passing under the tubes to the other end of the boiler, return through the flue *C* to the front again, and are finally discharged into the chimney by the side flues *D D*.

In Figure 92, *S* is the *safety-valve*. The weight acting on the lever keeps the valve closed until the pressure of the steam in the boiler becomes too great for safety, when it opens and allows a part of the steam to escape, and thus reduces the pressure. *n* is the tube through which water is supplied to the boiler; *m* the tube by which the steam is sent to the cylinder. *T* is the *man-hole*, through which workmen can enter the boiler to clean or repair it. *s* is an alarm whistle, so arranged that it is opened by the float *E* when the water sinks too low in the boiler. *P* is a contrivance for showing the depth of water in the boiler by the rising and falling of the weight *a*, which is connected by the lever with the float *F*. A simpler and better arrangement for the same purpose consists of a strong glass tube placed outside the boiler, but communicating with the

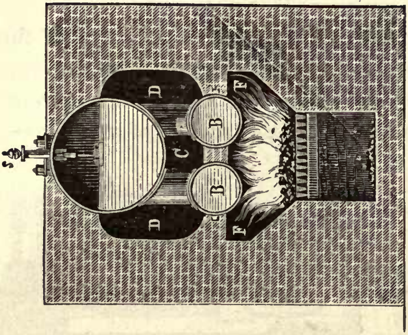


Fig. 93.

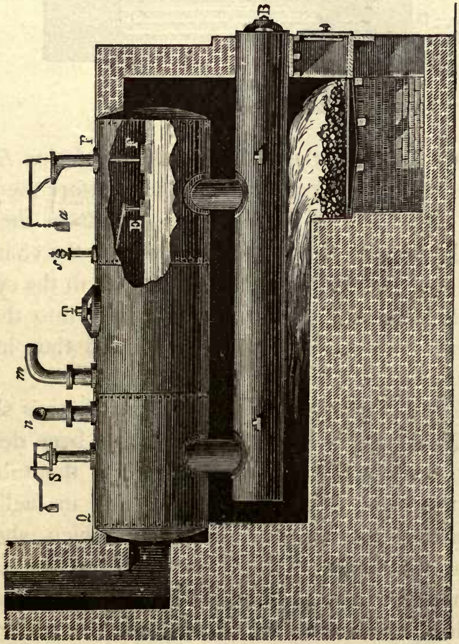
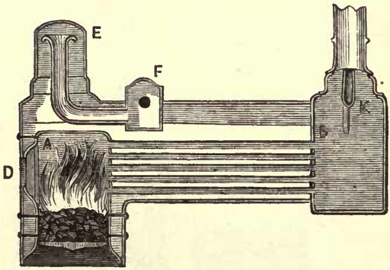


Fig. 92.

water within. The water in this tube stands of course at the same height as that in the boiler (18).

Figure 94 represents the usual form of the boiler of a locomotive engine. The furnace or *fire-box*, *A*, is within the boiler, and is surrounded by water except beneath and at the door *D*. A large number of stout tubes extend from

Fig 94.



the fire-box through the boiler to the *smoke-box B*. The hot gases and smoke pass through these before they escape into the chimney. *E* is the *steam-dome*, from the top of which a large tube conveys the steam into the chamber *F*, from which it passes by tubes on each side to the cylinders. The waste steam from the cylinders passes into the chimney through two pipes meeting at *K*, and thus increases the draught of the furnace.

131. *The Locomotive Engine.*—This machine is shown in full in Figure 95. The boiler *X X* has just been described. *D* is the fire-box; *Y*, the smoke-box; *a*, the tubes connecting the two; *O*, the door for putting in fuel; *n*, the glass water-gauge, already described, which shows the height of the water in the boiler; *H*, the vent-cock, by which the water can be drawn off from the boiler; *R R*, the feeders which conduct water from the *tender* to two force-pumps (not seen in the Figure) by which it is forced into the boiler; *i*, the safety-valves, kept down by spiral

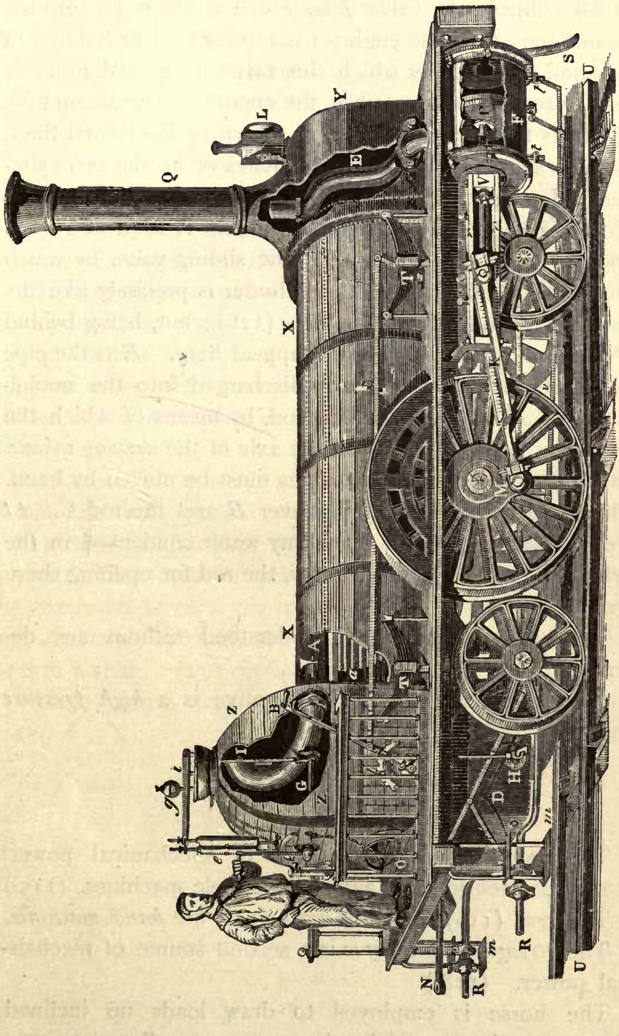


Fig. 95.

springs in the cases *e*; *g*, the steam-whistle; *G*, a rod which controls the valve *I* by which steam is let into the steam-pipe *A*. The engineer is represented as holding in his hand the lever by which this valve is opened more or less, to regulate the speed of the engine. The steam-tube *A* passes through the boiler, as shown by the dotted lines, into the smoke-box, where it branches off to the two cylinders. In this engine there is no chamber like that marked *F* in Figure 94. One of the cylinders is seen at *F*, laid open to show the piston *P*. The sliding valve by which the steam is admitted to the cylinder is precisely like the one figured and described above (126); but, being behind *F* under the boiler, it does not appear here. *E* is the pipe by which the waste steam is discharged into the smoke-pipe *Q*. *K* is the connecting-rod, by means of which the piston turns the crank *M* on the axle of the *driving wheels*. In starting the engine the valves must be moved by hand. This is done by means of the lever *B* and the rod *C*. *t t* are stop-cocks, through which any water condensed in the cylinders can be driven out; *v*, the rod for opening these cocks.

The other parts will be understood without any description.

It will be seen that the locomotive is a *high pressure* engine.

SUMMARY.

The *human hand* is a source of mechanical power. It may be used to work any of the simple machines. (115.)

The *crab* (116) and the *derrick* (117) are *hand machines*.

The *strength of the horse* is a second source of mechanical power. (118.)

The horse is employed to draw loads up inclined planes; to elevate weights by means of pulleys; to turn a crank or shaft; and to turn a wheel by treading upon a movable inclined surface in the form of an endless platform. (119.)

The *wind* is a third source of mechanical power.

This source of power is employed to propel ships and to drive windmills. (120.)

The *downward* and *lateral pressure of water* is a fourth source of mechanical power. (121.)

The downward pressure of water is made to turn a *vertical* water wheel. (122.)

The lateral pressure of water is made to turn a *horizontal* or *reaction* water wheel. (123.)

The *turbine wheel* is a reaction wheel, and the most efficient water wheel known. (124.)

The *elastic force of steam* is a fifth source of mechanical power. (125.)

The machine by which this source of power is applied is called a *steam engine*. (126.)

The essential parts of the steam engine are the *boiler*, in which the steam is generated; the *cylinder*, in which the expansive force of the steam is made to work a piston; and the *crank*, by which the motion of the piston is made to turn a shaft. (130, 126.)

Steam engines may be either of *high* or *low pressure*. (129.)

PART SECOND.

SOUND, LIGHT, HEAT, AND ELECTRICITY.

I.

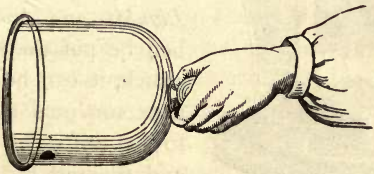
SOUND.

NATURE AND PROPAGATION OF SOUND.

SOUND-WAVES.

1. *A Sounding Body is a Vibrating Body.* — If a glass bell-jar held by the knob be struck with the knuckle, it gives out a sound. If a bit of metal, ivory, or other hard substance be placed within the bell, as seen in Figure 1,

Fig. 1.



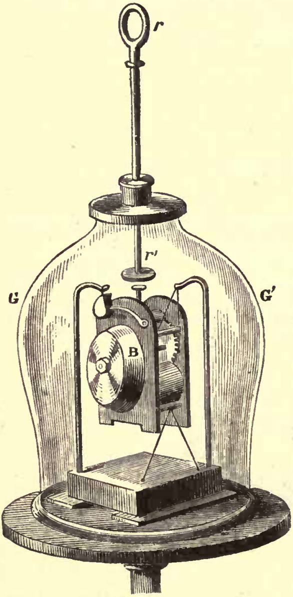
it is tossed up and down rapidly, showing that the bell is vibrating.

By similar experiments, it is found that every body is vibrating while giving out sound, and that it is only by causing a body to vibrate that it can be made to give out sound.

2. *Sound will not pass through a Vacuum.* — In Figure 2, the bell *B* is suspended by silk threads under the receiver of the air-pump. The bell is struck by means of clock-work, which can be set in motion by the sliding-rod *r*. If the bell be struck before exhausting the air, it can be distinctly heard; but as the air is exhausted, the sound be-

comes fainter and fainter, until at last it can hardly be perceived even with the ear close to the receiver. Sound, then, cannot pass through a vacuum.

Fig. 2.



The slight sound which is heard is transmitted by the little air left in the receiver, and by the cords which hold up the bell.

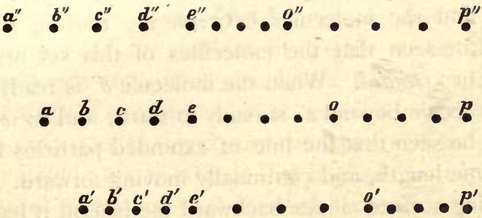
3. *Sound passes through all Gases.* — If hydrogen or any other gas be now allowed to pass into the receiver, the sound of the bell is heard again. It will be noticed that the sound is different in different gases.

4. *Sound passes through Liquids and Solids.* — If a bell be put under water and struck, it can be heard. If a person puts his ear close to the rail of an iron fence, and the rail be struck at a considerable distance, he hears the blow twice. The first sound comes through the rail; the second, which soon follows, comes through the air. These experiments show that sound passes through liquids and solids.

A slight scratch upon the iron rail, which could not be heard at all through the air, is heard distinctly when the ear is placed against the rail; showing that the solid transmits the sound better than the air. By placing the ear near the ground, the tramp of horses or the tread of men can be heard at a great distance, the sound being conveyed by the solid earth.

5. *Sound is propagated by means of Vibrations.* — We have seen (1) that sound is produced by vibrations. We next inquire how it is propagated. Let us first examine the condition of the molecules of the air in front of the sounding body. Let the middle line of dots in Figure 3

Fig. 3.



represent the position of the molecules when at rest. These molecules, as we have learned, are not in contact, and they are kept apart by an elastic force acting between them like a bent spring. Now, as the vibrating surface moves forward it pushes the molecules of the air before it; but, since it takes time to transmit the motion from molecule to molecule, they do not all move on together. The lower line of dots in the figure represents their condition when the vibrating surface has ceased to move forward. The molecule *a'* is just ready to come to rest, and the molecule *e'* just ready to begin to move, while all the molecules between are moving forward. It will be seen that the molecules between *a'* and *e'* are crowded together, or *compressed.* Just as the molecule *b'* comes to rest, the molecule beyond *e'* will begin to move; when *c'* comes to rest, the second molecule beyond *e'* begins to move; and so on. Thus the line of compressed molecules keeps of the same length, and continually moving forward.

Suppose the surface to be at rest at *a*, and to move backward instead of forward. The elastic force acting between the molecules in front of it will cause them to follow it one after another. If it is just as long in going backward as forward, the molecule *e* will be just ready to start when the molecule *a* stops. The upper line of dots represents the condition of the molecules when the vibrating surface has ceased to move backward. The molecule a'' is just ready to stop, and the molecule e'' just ready to start, and the molecules between are moving backward. It will be seen that the molecules of this set are spread apart, or *extended*. When the molecule b'' is ready to stop, the molecule beyond e'' is ready to start; and so on. Thus it will be seen that the line of extended particles keeps of the same length, and continually moving forward. As the vibrating surface moves backward the instant it has moved forward, the set of extended particles follows on directly after the set of compressed particles; and these two sets are sent out one after the other as long as the body is sounding; that is, if from a'' to e'' we have a set of extended particles, from e'' to o'' we shall have a set of compressed particles, from o'' to p'' a set of extended particles, and so on. It will be noticed that the molecules in the first set are moving forward; those in the second set, backward; those in the third set, forward; and so on. Of course each molecule is merely swinging backward and forward, or *vibrating*. We see, then, that when a body is sounding, the molecules of air about it are made to vibrate, and that they vibrate in *sets*. Two successive sets of these vibrations constitute what is called a *wave* of sound; that is, in the figure the portion of the upper line of dots from a'' to o'' is a wave. These sound-waves run out from a sounding body in every direction, just as the waves in water spread away in circles from the point where a stone has been thrown into it. So long as the sound-waves are passing through the air, their outline is spherical.

In like manner, sound is propagated through solids and liquids by means of vibrations.

Sound, then, is produced by vibrations, and these vibrations are passed on from molecule to molecule through the intervening bodies to the ear.

It will now be seen why sound cannot pass through a vacuum.

6. *The Intensity of Sound depends upon the Amplitude of the Vibrations.* — If the bell-jar in Figure 1 be struck lightly, it will give out a faint sound, and the bit of metal will be but slightly agitated ; if it be struck a harder blow, it will give out a louder sound, and the metal will be more violently agitated. It is evident that in the latter case the bell-jar moves backward and forward through a greater space than in the former ; in other words, that the *amplitude* of its vibrations is greater. The intensity of sound, then, depends upon the amplitude of the vibrations of the sounding body.

7. *The Intensity of Sound diminishes as the Square of the Distance of the Sounding Body increases.* — If we place a bell ten yards off, and four bells of the same size twenty yards off, we shall find that the sound of the one bell will be just equal to that of the four bells. At the distance of thirty yards, nine bells would be necessary to produce a sound equal to that of the one bell at ten yards. Sound, then, diminishes in intensity as the square of the distance from the sounding body increases. This is as we should expect. As the sound-waves spread away in all directions from the sounding body, a greater and greater number of particles of air must be set in motion, and the motion of each must be more feeble ; and, since the surfaces of spheres increase as the squares of their radii, the number of particles to be set in motion increases as the square of the distance from the sounding body.

8. *Speaking-Tubes.* — If the sound-waves are prevented

from spreading in all directions, the particles of air lose little of their motion, and the sound little of its intensity. Thus Biot found that through one of the water-pipes of Paris words spoken in a very low tone could be heard at the distance of about three quarters of a mile. The sides of the pipe kept the sound-waves from spreading. In the same way, conversation can be carried on between distant parts of a large building by means of small tubes, called *speaking-tubes*.

9. *Sound travels through the Air at the Rate of* 1,090 *Feet a Second.* — The velocity of sound in air has been several times determined by experiment. In 1822, the French Board of Longitude chose two heights near Paris, and from the top of each fired a cannon at intervals of ten minutes during the night. The time between seeing the flash and hearing the report was carefully noted at both stations, and the average of the results showed that sound travels through the air at the rate of 1,090 feet a second. In such experiments, the time taken by the light to pass between the stations is too small to be perceived.

10. *The Observed and the Computed Velocity of Sound.* — From the known elasticity and density of air, Newton computed that the velocity of sound should be 916 feet a second. That the observed velocity is greater is due to the change in the elasticity of the air in the two portions of the sound-wave, owing to the development of heat in the compressed part and its absorption in the extended part. That heat is developed by compression of the air may be shown by putting some tinder in a *fire syringe* (Figure 4) and quickly pushing down the piston: the tinder will take fire. Now heat increases the elasticity of the air, and the increased elasticity in the compressed part of the wave has the same effect as putting stiffer springs between the molecules in front, so that they will impart

their forward motion to one another more promptly ; while the diminished elasticity in the extended portion has the same effect as placing weaker springs between the molecules behind, so that the molecules can also return more promptly. Thus it will be seen that the change of elasticity in the two portions of the wave, by the development and absorption of heat, increases the rapidity with which the molecules can impart their vibratory motion to one another ; and this rapidity is the velocity of sound.

Fig. 4.

11. *The Velocity of the Sound-wave depends on the Elasticity as compared with the Density of the Medium.* — As long as the elasticity remains the same, the velocity of the sound-wave will be diminished by increasing the density ; for, the greater the density, the greater the number of molecules to be put in motion, and the slower the motion will be transmitted. While the density remains the same, the velocity increases with the elasticity, as we have seen above. This explains the fact that the velocity of sound at a great height in the air is the same as near the earth. As we ascend, the temperature falls and the elastic force of the air becomes less, but the density of the air diminishes at the same rate. If the density and elasticity both increase at the same rate, the velocity will remain the same. The greater, then, the elasticity of the medium compared with its density, the greater the velocity of sound. It will be shown farther on how the velocity of sound in different gases can be ascertained.

12. *The Velocity of Sound in Water is about* 4,700 *Feet a Second.* — This was determined at the Lake of Geneva, in 1826, by Colladon and Sturm. They found that, when a bell was struck under water on one side of the lake, the sound could be distinctly heard at a distance of nine miles

on the other side by putting the ear to one end of a tube whose other end was in the water. It was thus found that the velocity of sound in water is about 4,700 feet a second. The method of finding how fast sound travels in different liquids will be explained in another place.

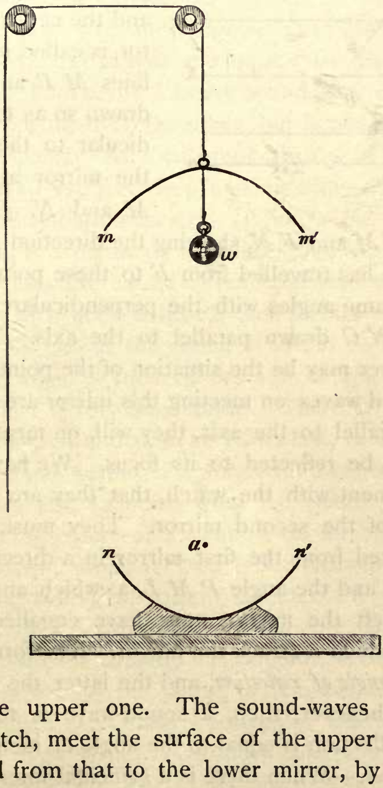
13. *Sound travels through Solids faster than through Air.* — It is found by the experiment with the iron rail mentioned above (4) that the velocity of sound in a solid body is greater than in the air. It will be shown hereafter how we can find the velocity of sound in solids.

14. *On meeting a Medium of different Density the Sound-wave is partially reflected.* — The transmission of vibrations in a sound-wave from one particle to another may be illustrated by means of two ivory balls hung side by side. If the balls are of the same size, and one be raised and dropped against the other, the first gives up all its motion to the second and itself comes to rest. If the first ball is smaller than the second and be let fall against it, the second moves forward and the first rebounds. If the first is larger than the second, it follows the second a little way and then falls back again. In the first case the balls illustrate the condition of the molecules in a uniform medium: each molecule gives up all its motion to the next, and would come to rest were it not kept vibrating by the sounding body behind. In such a medium, then, the sound-wave moves steadily forward. In the second case the balls illustrate the condition of the molecules of a rarer medium contiguous to those of a denser medium. When the sound-wave meets this denser medium, the molecules of the rarer medium give up only a part of their motion to those of the denser, and themselves rebound, giving rise to a reflected wave. In the third case the balls illustrate the condition of the molecules of a denser medium contiguous to those of a rarer medium. Here it will be seen that the sound-wave is partially reflected on meeting a rarer medium.

Whenever, then, the sound-wave meets a medium of different density, it is partially reflected.

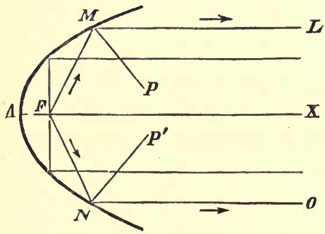
15. *When a Sound-wave is reflected, the Angle of Reflection is equal to the Angle of Incidence.* — In Figure 5 we have two parabolic mirrors, with a watch placed in the

Fig. 5.



focus of the upper one. The sound-waves spread out from the watch, meet the surface of the upper mirror, and are reflected from that to the lower mirror, by which they are again reflected. If the mirrors are several yards apart, it will be found that the ticking of the watch can be heard distinctly on placing the ear at *a*, the focus of the lower mirror, though it cannot be heard at any other point near that mirror. This shows that the reflected sound-waves are all concentrated at the point *a*. By what path have they reached this point? In Figure 6, *F* is the focus of the parabolic mirror *N A M*, and the line *A X*, passing through the focus and the centre of the mirror, is called its *axis*. The lines *M P* and *N P′* are drawn so as to be perpendicular to the surface of the mirror at the points *M* and *N*. If we draw

Fig. 6.



the lines *F M* and *F N*, showing the direction in which the sound-wave has travelled from *F* to these points, they will make the same angles with the perpendiculars as the lines *M L* and *N O* drawn parallel to the axis. This will be true whatever may be the situation of the points *M* and *N*. If the sound-waves on meeting this mirror are all reflected in lines parallel to the axis, they will, on meeting the second mirror, be reflected to its focus. We have found, by the experiment with the watch, that they are reflected to the focus of the second mirror. They must, then, have been reflected from the first mirror in a direction parallel to its axis; and the angle *P M L*, at which any portion of the wave left the mirror, must have equalled the angle *F M P* at which it struck the mirror. The former angle is called the *angle of reflection*, and the latter the *angle of incidence*. Whenever, then, a sound-wave is reflected, the angle of reflection is equal to the angle of incidence.

16. *Echoes.*—When there is a sufficient interval between the direct and the reflected sound, we hear the latter as an *echo*. The reflected sound has the same velocity as the direct sound, so that the echo of a pistol-shot from the

face of a cliff 1,090 feet distant is heard two seconds after the explosion.

An echo in Woodstock Park repeats seventeen syllables by day, and twenty by night; one on the banks of the Lago del Lupo, above the fall of Terni, repeats fifteen. The tick of a watch may be heard from one end of the abbey church of St. Albans to the other. In Gloucester Cathedral, a gallery of an octagonal form conveys a whisper seventy-five feet across the nave. In the whispering gallery of St. Paul's, the faintest sound is conveyed from one side to the other of the dome, but is not heard at any intermediate point. At Carisbrook Castle, in the Isle of Wight, is a well 210 feet deep and 12 wide. The interior is lined with smooth masonry. When a pin is dropped into the well, it is distinctly heard to strike the water.

In some cases the sound is reflected several times, and a succession of echoes is heard, each feebler than the preceding, since a part of the sound is lost at each reflection. In mountain regions such echoes are common, and sometimes the effect is very remarkable. There is a deep valley called the Ochsenthal, near Rosenlaui, in Switzerland, where the echoes warble in a wonderful manner.

Sounds are also reflected from the clouds. When the sky is clear, the report of a cannon on an open plain is short and sharp; while a cloud is sufficient to produce an echo like the rolling of distant thunder. A feeble echo also occurs when sound passes from one mass of air to another of different density. Humboldt relates that, from a certain position on the plains of Antures, the sound of the great falls of the Orinoco resembles the beating of a surf upon a rocky shore, being much louder by night than by day. This is not due to the greater stillness of the night, for the hum of insects and the roar of beasts render the night much noisier than the day. But between the place where Humboldt was and the falls lay a vast grassy plain, with many bare rocks rising from it. When exposed to the sun, these rocks became much hotter than the adjacent grass; over each of them, therefore, rose a column of heated air, less dense than that which surrounded it. Thus by day the sound had to pass through an atmosphere which frequently changed its density; the partial echoes where the rare and dense air met were incessant, and the sound was consequently enfeebled. At night there were no such differences of temperature, and the sound-waves, travelling through an atmosphere of uniform density, reached the ear without any loss from reflection.

17. *When a Sound-wave passes obliquely into a Medium of different Density it is refracted.* — Let *a b* (Figure 7) be

Fig. 7.

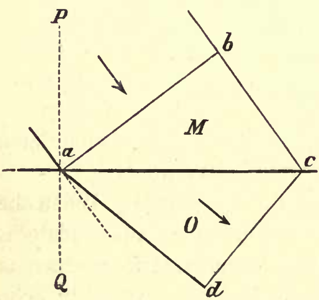
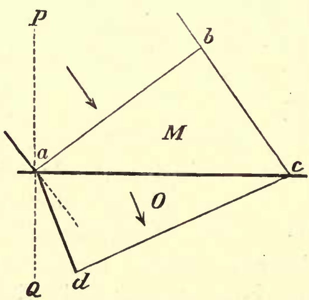


Fig. 8.



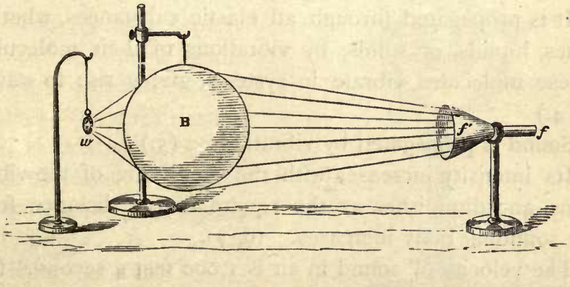
a portion of a sound-wave moving in the direction of the arrow, and *a c* be the surface of a medium *O* of different density from *M*, in which the wave has been moving. If the elasticity of *O* is such that the wave will move faster in it than in *M*, the portion *a* of the wave which enters *O* first will move on faster than the portion *b* while the latter is moving in *M*. When *a b* is wholly within *O*, the second arrow shows the direction in which it will be moving; and it will continue to move in this direction so long as it is wholly in this medium. When the direction of a wave is thus bent, it is said to be *refracted.* In this case it is bent away from a perpendicular *P Q* drawn to the surface of the medium *O*.

If the elasticity of *O* is such that the sound-wave moves slower in it than in *M*, the portion *a* of the wave (Figure 8), when it has entered *O*, moves slower than *b* while the latter is in *M*. In this case it will be seen that the direction of the wave will be bent towards the perpendicular *P Q*.

It is evident that, if *a b* had not met the medium *O* obliquely, both ends of it would have entered *O* at the same time, and its direction would not have been changed.

We see, then, that when a sound-wave passes obliquely into a medium of different density, it is refracted, and that, if it travels more rapidly in the new medium, it will be bent away from a perpendicular drawn to the surface of that medium; while, if it travels less rapidly in the new medium, it will be bent towards a perpendicular drawn to the surface of that medium.

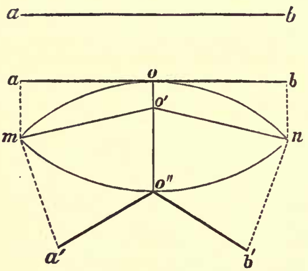
Fig. 9.



This refraction of a sound-wave has been shown by the experiment illustrated in Figure 9. *B* is a collodion balloon filled with carbonic acid gas; *w* is a watch hung near it; and f' is a glass funnel. By placing the ear at f and moving the funnel about, a point will be found where the ticking of the watch will be louder than elsewhere. This shows that the sound-waves have been converged to that point.

Figure 10 shows how the sound-waves are refracted in passing through the carbonic acid. *a b* is a portion of the sound-wave. In passing into the carbonic acid, — a medium in which it moves more slowly than in air, — it is bent into the form of *m o′ n*. On passing out from the carbonic acid, it is bent still farther in the same direction, and thus the two parts of the wave are made to converge.

Fig. 10.



SUMMARY.

Sound originates in a vibrating body. (1.)

It is not propagated through a vacuum. (2.)

It is propagated through all elastic substances, whether gases, liquids, or solids, by vibrations of their molecules. These molecules vibrate in systems, giving rise to waves. (3, 4.)

Sound is propagated by vibrations. (5.)

Its intensity increases with the amplitude of the vibrations, and diminishes as the square of the distance from the sounding body increases. (6, 7).

The velocity of sound in air is 1,090 feet a second. (9.)

Its observed velocity is greater than its velocity as computed by Newton, owing to the heat developed in the compressed portion of the wave. (10.)

The velocity of sound in any medium depends upon its density as compared with its elasticity. (11.)

The velocity of sound in water is about 4,700 feet a second. Its velocity in solids is greater than in the air. (12, 13.)

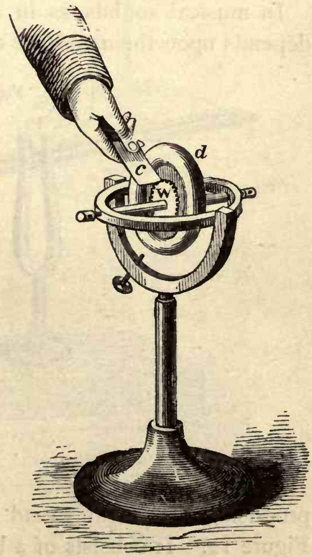
On meeting a medium of different density, the sound-waves are partially reflected and partially transmitted. The transmitted portion is refracted, unless the wave meets the surface of the medium perpendicularly. (14, 17.)

Echoes are due to reflected sound-waves. (16.)

MUSICAL SOUNDS.

18. *Difference between Noise and Musical Sounds.* — In Figure 11 we have an instrument called the *gyroscope*, consisting mainly of a heavy brass ring *d* surrounding a disc which rests upon a steel axis. To this axis is fastened a small toothed wheel *W.* By winding a string round the axis and then drawing it suddenly out, the ring and the toothed wheel are made to spin rapidly. If a card *c* be held against the edge of the wheel as it rotates, a very shrill musical sound is produced. If the thumb be placed a moment against the ring, the speed of its rotation is checked somewhat, and the sound becomes less shrill. The more the speed is diminished, the less shrill the

Fig. 11.



sound becomes, until finally we hear the separate taps of the teeth against the card.

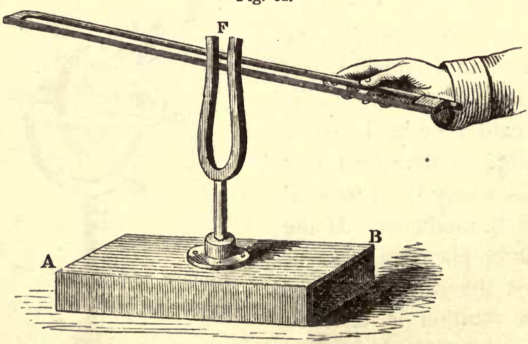
We see, then, that when the taps are frequent enough, they blend so as to produce one continuous sound. Such a continuous sound is called a *musical sound.*

In this experiment the card is made to vibrate by striking the teeth of the wheel, and, as the teeth are at equal distances, the vibrations follow one another at equal intervals. A musical sound, then, is one in which the vibrations recur at regular intervals. If they do not recur at regular intervals, the sound is called a *noise.*

19. *The Pitch of Musical Sounds.* — We have seen that, the faster the wheel turns, the shriller is the sound, or, in other words, the *higher* its *pitch.* Of course, the faster the wheel turns, the more rapid are the vibrations of the card. Hence the pitch of musical sounds depends on the rapidity of the vibrations.

In musical sounds, as in all other sounds, the *loudness* depends upon the *amplitude* of the vibrations.

Fig. 12.

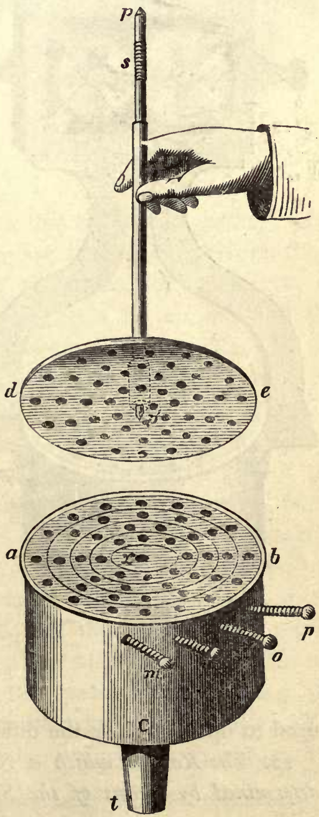


20. *The Tuning-Fork.* — A convenient instrument for producing a musical sound is the tuning-fork, shown in Figure 12. It consists of a bar of steel bent into the form

of the letter *U*, and attached to a standard. *A B* is a wooden case open at both ends, by which the intensity of the sound produced by the fork is increased. The fork may be set vibrating by striking it, or by drawing a violin bow across it. The elasticity of the steel causes the prongs to vibrate regularly, and thus to give out a musical sound.

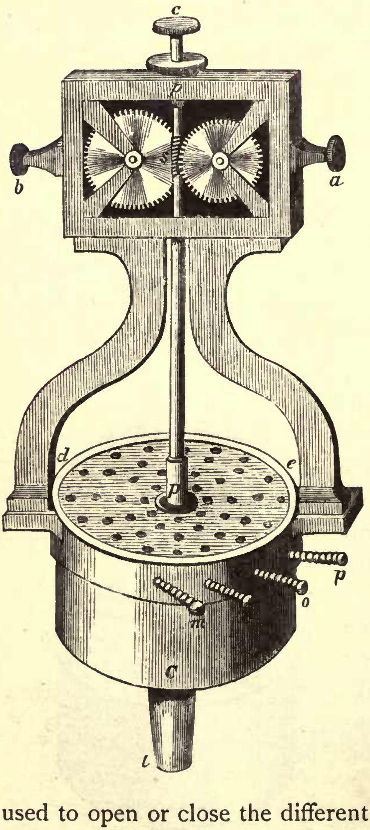
21. *The Siren.* — The *siren* is an instrument for producing musical sounds, and at the same time registering the number of vibrations. It consists (Figure 13) of a brass cylinder *C*, having a tube *t* opening into it at the bottom, and closed at the top by a brass plate *a b*. This plate is pierced with four series of holes arranged in circles. The innermost series contains 8, the next 10, the next 12, and the last 16 holes. *d e* is a brass disc pierced with four series of holes arranged like those below. The holes in the plate *a b* are inclined a little in one direction, and those in *d e* a little in the opposite direction. Through the centre of the disc passes a steel axis, the lower end *p′* of which fits into the hole *x* in *a b*. The disc is made to rotate by blowing into

Fig. 13.



the tube *t*. The current of air striking against the slanting sides of the holes in *a b* is directed against the sides of the holes in *d e*, and thus pushes it round. As it rotates, the holes in *a b* are alternately opened and closed, so that the air escapes from the cylinder in a regular succession of puffs, giving rise to vibrations, which produce a musical sound.

Fig. 14.



The number of times the disc rotates is registered by the apparatus shown in the upper part of Figure 14. On the axis of the disc is an endless screw *s*, which carries a pair of toothed wheels. These are connected with pointers moving over dial-plates on the front of the instrument, as shown in Figure 15.

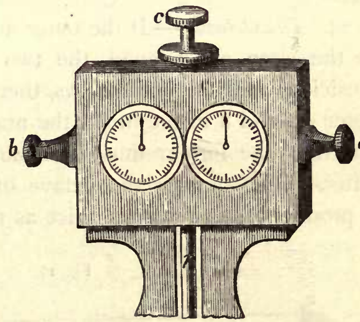
By pushing upon *a* and *b* (Figure 14) the registering apparatus can be thrown into or out of action at any moment.

The stops *m*, *n*, *o*, *p*, seen in Figure 14, are used to open or close the different sets of holes.

22. *The Rate at which a Sounding Body vibrates may be determined by means of the Siren.* — If we force air into

the siren by means of a bellows, the disc is made to rotate faster and faster, and the pitch of the sound produced rises higher and higher, as the force of the blast increases. In this way the siren may be made to give a sound of the same pitch as that of a tuning-fork, or any other sounding body; and, by means of the registering apparatus, the number of vibrations in a second may be ascertained. Suppose, for instance, that the outer set of holes is open, and the pointers show that the disc is making 1,440 turns in a minute. As there are 16 holes in this set, there will be 16 puffs of air, or vibrations, for each turn, or 23,040 in a minute. Dividing this by 60, we find the number of vibrations in a second to be 384. If the tuning-fork is giving out the same note as the siren, it is making 384 vibrations in a second.

Fig. 15.



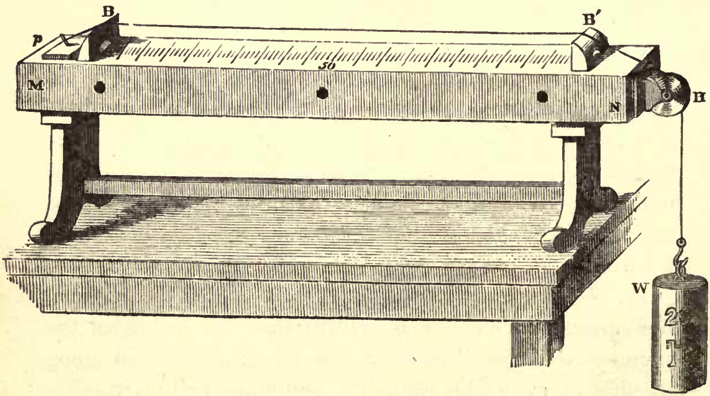
23. *The Length of the Sound-wave.* — From the explanation given above (5), it is evident that the length of the sound-wave is the distance the motion is transmitted along the line of molecules while the sounding body is making one vibration. The faster, then, a body vibrates, the shorter is the sound-wave; and, as we know the velocity of sound in air, we can readily find the length of the sound-wave when we know the rate at which the body vibrates. Suppose, for instance, that the tuning-fork is making 384 vibrations in a second. As the velocity of sound in air is 1,120 feet a second* at the ordinary temperature, the

* 1,090 feet per second is the velocity at the freezing point.

length of the sound-wave will be equal to 1,120 divided by 384, or about 3 feet. The waves produced by a man's voice in ordinary conversation are from 8 to 12 feet in length; those produced by a woman's voice, from 2 to 4 feet.

24. *The Octave.* — If the outer and inner circles of holes in the siren are opened, the two sounds differ by what musicians call an *octave.* As there are 16 holes in the outer set and 8 in the inner, the number of vibrations produced by the former must be double that produced by the latter. One sound is the octave of another, then, when it is produced by vibrations twice as rapid.

Fig. 16.



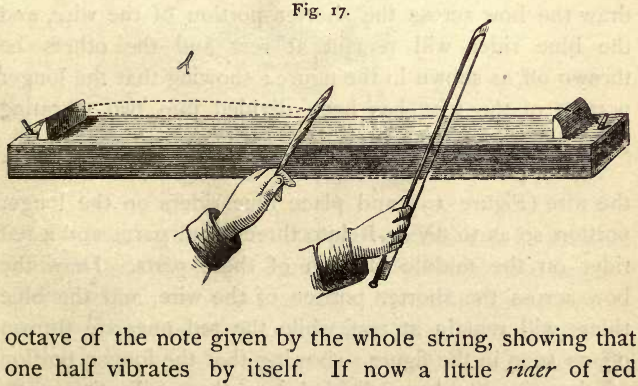
25. *The Sonometer.* — Another important instrument for investigating the formation of musical sounds is the *sonometer* (*sound-measurer*). The instrument is shown in Figure 16. It consists of the sounding-board *M N*, above which the string *B B'* is stretched upon two movable bridges by means of the weight *W*. It is used to illustrate the laws of the vibrations of strings.

26. *The Rapidity with which a String vibrates is inversely*

as its Length. — Cause the string $B\ B'$ to vibrate by pulling it to one side, or drawing a bow across it, and notice the pitch of the sound. Place one of the movable bridges at the centre of the string, so as to divide it into two equal parts, and cause either part to vibrate. The sound will be the octave of the one given out by the whole string. We have already learned that the octave of a note is produced by double the number of vibrations (24). The half of a string, then, vibrates twice as rapidly as the whole string, when the tension of the string remains the same. It can, moreover, be proved, both by calculation and by the siren, that the half of a string vibrates with exactly twice the rapidity of the whole. In the same way, it can be proved that one third of a string vibrates with thrice the rapidity of the whole; and so on. In general terms, then, while the string is equally stretched, the rapidity of its vibrations is inversely as its length.

27. *The Formation of Nodes.** — If we hold a feather against the centre of the wire of the sonometer (Figure 17), and draw a bow across one half of it, we get the

Fig. 17.



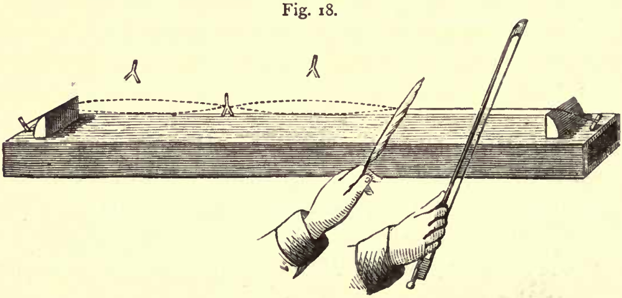
octave of the note given by the whole string, showing that one half vibrates by itself. If now a little *rider* of red

* See Appendix, I.

paper be placed across the middle of one part of the string, and the other part be made to vibrate while the feather is still held at the centre, the rider is thrown off, showing that both halves of the string vibrate. These vibrating halves are separated by a *node*, or stationary joint, formed where the feather touches the string.

Hold now the feather one third of the way from the end of the wire (Figure 18), and place a blue rider on the

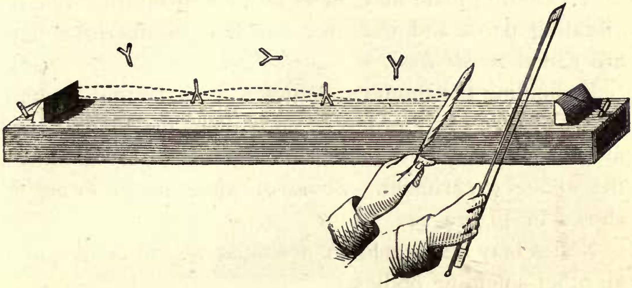
Fig. 18.



longer portion of the wire, so as to divide it into two halves, and red ones on the middle of these halves. Now draw the bow across the shorter portion of the wire, and the blue rider will remain at rest and the others be thrown off, as shown in the figure; showing that the longer portion of the wire has been divided into two vibrating parts separated by a node.

Again, place the feather so as to cut off one fourth of the wire (Figure 19), and place blue riders on the longer portion so as to divide it into three equal parts, and a red rider on the middle of each of these parts. Draw the bow across the shorter portion of the wire, and the blue riders will remain at rest, while the red ones are thrown off, as seen in the figure; showing that the longer portion of the wire has been divided into three vibrating parts separated by two nodes.

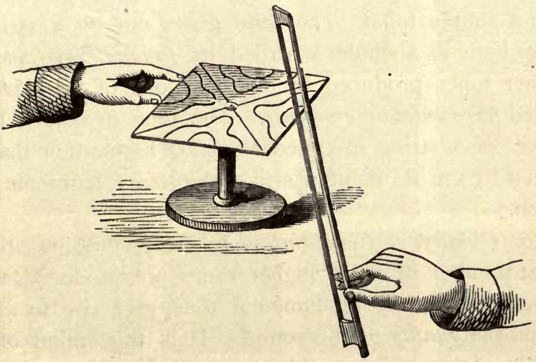
Fig. 19.



In the same way the wire may be divided into five, six, or any number of vibrating parts separated by nodes.

28. *Formation of Nodes in Vibrating Plates.* — In Figure 20 we have a metallic plate supported at its centre. If

Fig. 20.



fine sand be sprinkled over the plate, and a bow be drawn across the middle of one edge while the thumb and finger are held against the opposite edge, the sand instantly collects into lines, as seen in the figure; showing that the vibrating plate is at rest along these lines. The sand has all been tossed away from the vibrating portions between the lines.

A vibrating plate may, then, be broken up into different vibrating parts, and the lines which separate these parts are called *nodal lines.*

By holding the thumb and finger against different parts of the plate, a great variety of nodal lines may be obtained, all of which may be made visible by means of sand, as in the above experiment. Some of these nodal forms are shown in Figure 21.

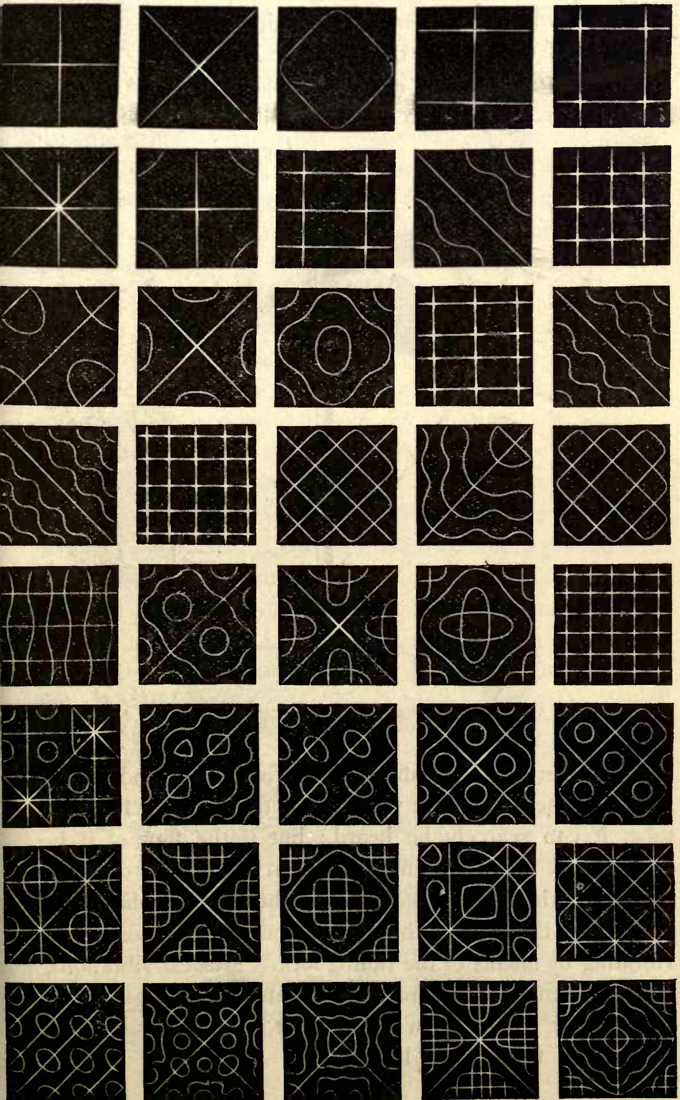
Nodes may be formed in a similar way in bells, and in all other sounding bodies.

29. *Overtones or Harmonics.* — We have now seen that a string or other sounding body can either vibrate as a whole, or divide itself into a number of equal parts, each of which vibrates independently. It is found that, even when it is made to vibrate as a whole, it always does at the same time vibrate in parts; so that a vibrating body never gives out a simple tone. The tone given out by a string or other body as a whole is called its *fundamental note;* the higher tones produced by the vibrations of the parts are called *harmonics* or *overtones.* The tone produced by the halves of a string is called the *first* harmonic; that produced by the thirds of a string, the *second* harmonic; and so on.

30. *Quality, or Clang-tint.* — In every vibrating string a great number of these higher tones are produced, which, mingling with the fundamental tone, give rise to what is called the *quality* of the sound. It is this union of high and low tones which enables us to distinguish one musical instrument from another. A flute and a violin, though tuned to the same fundamental note, do not give the same sound. The overtones of the one are different from those of the other; and the mixtures formed by these and the fundamental note in the two cases are therefore different.

Professor Tyndall, following the Germans, calls the mixture of the fundamental tone and its overtones a *clang*, and

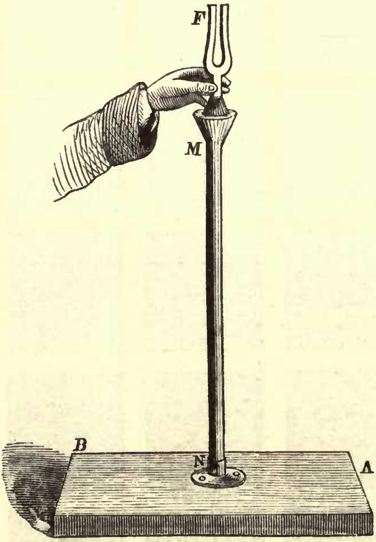
Fig. 21.



the *quality* of the clang the *clang-tint*. Different mixtures of tones will have different clang-tints, just as different mixtures of colors have different tints.

31. *The Transmission of Musical Sounds through Liquids.* — In Figure 22, *M* is a long tube filled with water, which

Fig. 22.



is placed between the tuning-fork *F* and the sounding-box *A B*. If the fork be set vibrating in the air away from the tube, it can scarcely be heard; but if the foot of it be placed upon the water in the tube, it can be heard as distinctly as when it is placed upon the sounding-box. In both cases the box is the real sounding body, and is set vibrating by means of the tuning-fork. Musical vibrations, then, are transmitted through the water in the tube. In a similar way it has been found that musical sounds are transmitted through all liquids.

32. *Transmission of Musical Sounds through Solids.* — Professor Tyndall has shown the transmission of musical sounds through solids by the following experiment. He arranged a wooden rod thirty feet long so that it passed through a window in the ceiling of the lecture-room into the open air above. The lower end of the rod rested upon a sounding-box. An assistant on the roof struck a tuning-fork, but no sound could be heard from it until he held the stem against the end of the wooden rod, when the sounding-box at once gave out a musical sound. The pitch of the sound was exactly that of the tuning-fork, showing that the wood transmitted the vibrations without alteration. By using different forks, notes of different pitch were obtained. The results would have been the same had the wooden rod been ten times as long.

An experiment first tried by Wheatstone and repeated by Tyndall is even more striking. A piano was placed in a room underneath the lecture-room, separated from the latter by two floors. Through the two floors passed a tin tube $2\frac{1}{2}$ inches in diameter, with a wooden rod inside of it, the end of which projected into the lecture-room. The rod was clasped by India-rubber bands which completely closed the tube. The lower end of the rod rested upon the sounding-board of the piano. The piano was played, and no sound was heard in the lecture-room ; but when a violin was placed against the end of the rod, it became musical, not with the vibrations of its own strings, but with those of the piano. On taking away the violin, the music ceased ; but when a guitar was put in its place, the sounds were heard again ; and also when a sounding-box was substituted for the guitar. The end of the rod was then placed against the sounding-board of a harp, and every note of the piano was reproduced as before.

An ordinary music-box may be used instead of the piano in this experiment.

Musical sounds, then, like other sounds, are transmitted unchanged through solids, liquids, and gases.

33. *Sympathetic Vibrations.* — On the sonometer stretch two strings about three inches asunder. By means of a key, alter the tension of the strings, continually sounding both of them until they are brought into perfect unison. Place a little paper rider upon the middle of one of them, and agitate the other. The untouched string tosses off its rider, showing that it is thrown into vibration.

Every experiment with the riders and a single string described above (27) may be repeated with these two unisonant strings. Let us, for example, damp one of the strings at a point one fourth of its length from one of its ends; and let us place the red and blue riders formerly employed, not on the nodes and vibrating parts of the damped string, but at points upon the other exactly opposite to those nodes and vibrating parts. When the bow is passed across the shorter segment of the damped string, the four red riders on the adjacent string are unhorsed, while the three blue ones remain tranquilly in their places. Relax one of the strings so as to throw it out of unison with the other. All efforts to unhorse the riders are now unavailing. Strings, then, can readily take up from the air those vibrations which they can communicate to it, — that is, the vibrations which are synchronous to their own.

The influence of synchronism may be illustrated in a still more striking manner by means of two tuning-forks which sound the same note. Place two such forks, mounted on their resonant supports, upon the table, 18 inches asunder, and draw the bow vigorously across one of them. If now we stop the agitated fork, the sound is enfeebled, but by no means quenched. The vibrations conveyed through the air and through the wood have been taken up by the untouched fork, and it is this fork which we now hear. Attach a bit of wax to one of the forks, and sound it again; the very slight change in the rate of vibration has destroyed the sympathy between the two forks, and no response is now possible. Remove the wax, and the untouched fork responds as before. In this experiment the forks may be several feet apart. The vibrations may also be communicated through the air alone. Stop one of the forks, and cause the other to vibrate vigorously. Hold the case of the vibrating fork in the hand, and bring one of its prongs near the other fork, placing the prongs back to back. Extinguish the sound of the agitated fork, and the fork which a moment ago was silent continues to sound, having taken up the vibrations of its neighbor, which must have been transmitted to it through the air.

Remove one of the forks from its resonant case, and throw it into strong vibration. Held free in the air, its sound is inaudible. But now bring it close to the silent fork, and a full, mellow sound is heard, which is due, not to the fork first agitated, but to its sympathetic neighbor.

Various other examples of the influence of synchronism might be brought forward. If two clocks, for example, with pendulums of the same period of vibration, be placed against the same wall, and if one of the clocks be set going and the other not, the ticks of the moving clock, transmitted through the wall, will start its neighbor. The pendulum, moved by a single tick, swings through a very small arc, but it returns to the limit of its swing just in time to receive another impulse. In this way the impulses add themselves together so as finally to set the clock going, and in precisely the same way the vibrating particles of wood and air were enabled to cause the string and fork in the above experiment to vibrate. It is by this timing of impulses that a properly pitched voice can cause a glass to ring, and that the sound of an organ can break a particular window-pane.

When a body is thus thrown into vibration by its neighbor, its vibrations are said to be *sympathetic.*

A body which could originate only one kind of vibration could thus intercept only one kind of vibration; while those which can originate vibrations of various periods can intercept vibrations of all these periods. Plates and membranes are capable of originating vibrations of the greatest number of periods, and therefore of intercepting the greatest number of vibrations.

SUMMARY.

When the vibrations of a sounding body take place at regular intervals and often enough, they give rise to a *musical sound.* In a *noise* the vibrations follow one another at irregular intervals. (18.)

The *pitch* of the sound increases with the rapidity of the vibrations. (19.)

The *tuning-fork* is an instrument much used in the investigation of musical sounds. (20.)

By means of the *siren* we may ascertain the number of vibrations answering to any given pitch. (22.)

The length of the sound-wave decreases as the pitch rises. (23.)

A string may vibrate in segments separated by nodes. (27.)

Plates and all sounding bodies may vibrate in segments. (28.)

Sounding bodies always break up into segments so as to start vibrations of several periods at the same time. (29.)

The blending of these vibrations gives to the sound its *quality* or *clang-tint.* (30.)

Musical sounds are transmitted through solids, liquids, and gases. (31, 32.)

Any body can intercept and reinforce those vibrations which are synchronous with its own. (33.)

THE SUPERPOSITION AND INTERFERENCE OF SOUND-WAVES.

34. *The Superposition of Water-waves.*—It is well known that a great variety of waves may exist together on the surface of water. Thus in the ocean we may have the great tidal wave; upon the back of this, the billows raised by the wind; upon these, still smaller waves; and upon these, in turn, ripples of an endless variety of size and form. This carving of the surface by waves and ripples has its limit only in our powers of observation; yet every wave and every ripple retains a distinct existence amid the numberless other motions which disturb the water.

The law that governs this intermingling of innumerable waves is *that the resultant motion of every particle of water is the sum of the separate motions given to it.* Thus, any particle acted upon by two forces, both tending to raise it, will be lifted a distance equal to the sum of the distances which the forces acting separately would raise it. If acted upon by two forces tending to depress it, the particle would descend a distance equal to the sum of the distances which the forces acting singly would carry it. If one of the forces tends to raise the particle, and the other to depress it, the particle will move, in the direction of the greater force, a distance equal to the difference of the distances which the forces acting separately would carry it. By the *sum* of the motions, then, we mean the *algebraic* sum.

When two stones are cast into smooth water, 20 or 30 feet apart, round each stone is formed a series of expanding circular waves, every one of which consists of a ridge and a furrow. The waves at length touch, and then cross one another, carving the surface into little eminences and depressions. Where ridge coincides with ridge, we have the water raised to a double height; where furrow coincides with furrow, we have it depressed to a double depth. Where ridge coincides with furrow, we have the water reduced to its average level. The resultant motion of the water at every point is, as above stated, the algebraic sum of the motions impressed upon that point. And if, instead of two sources of disturbance, we had ten, or a hundred, or a thousand, the consequence would be the same: the law above enunciated would still hold good.

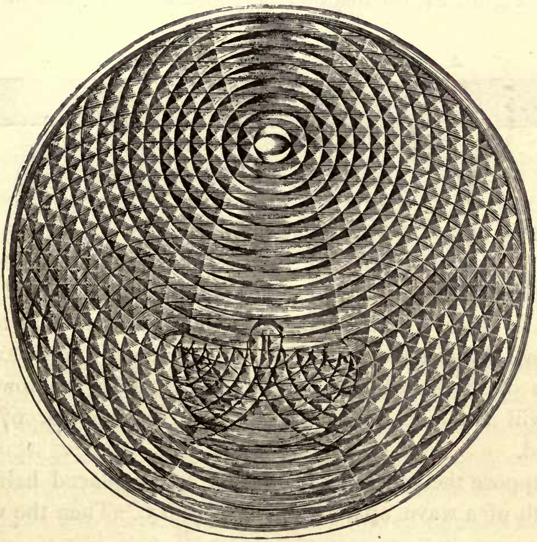
Instead of the intersection of waves from two distinct centres of disturbance, we may cause direct and reflected waves from the same centre to cross each other. These effects may be shown by reflecting upon a screen the light from ripples of water in a pan. When mercury is employed, the effect is more brilliant still. Here, by a proper mode of agitation, direct and reflected waves may be made to cross and interlace, and then again to disentangle themselves.

Figure 23 will give some idea of the beauty of these effects. It represents the forms produced by the intersection of direct and reflected water-waves in a vessel. The point of disturbance is marked by the smallest circle in the figure, and is midway between the centre and the circumference.

35. *Superposition of Sound-waves.* — In like manner a great variety of sound-waves may exist together in the air. For instance, in the playing of an orchestra all the instruments are sending forth waves at the same time, which traverse the air together; and, though we cannot see them, their separate existence is proved by the fact that the ear readily distinguishes the quality and pitch of the sound given by each instrument. In this way thousands of waves may be transmitted through the air at the same time without losing their individual character. The same law holds good here as in the case of water-waves;

namely, that every particle of air is affected by a motion which is the algebraic sum of all the single motions imparted to it. The most wonderful thing of all is, that

Fig. 23.



the human ear, though acted upon only by a cylinder of air not exceeding the thickness of a quill, can detect all the components of the motion of each particle, and thus single out any one sound from the confused mixture.

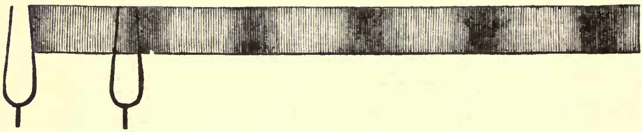
36. *Coincidence and Interference of Sound.*—If the sound-waves, in moving through the air, obey the same laws as water-waves, they ought, when meeting in such a way that the compression of one coincides with the compression of the other, or the extension of one with the extension of the other, to increase the volume of the wave; and, on the other hand, when meeting in such a way that the compression of one coincides more or less perfectly with the

extension of the other, the volume of the wave ought to be diminished. If the waves are exactly alike, and meet in exactly opposite phases, one ought to destroy the other.

In Figure 24, for instance, suppose we have two tuning-

Fig. 24.

B A C

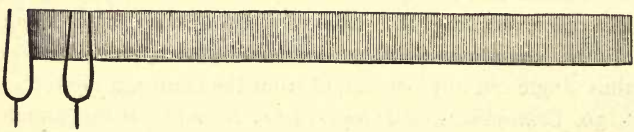


forks, *A* and *B*, vibrating at the same rate. Suppose that both begin to vibrate at the same time, and that they are placed the length of a wave apart. The fork *A* will then be ready to start a wave as often as the wave started by *B* reaches it, and the compressions and extensions of the successive waves, as they move on towards *C*, will coincide, and thus increase the volume of the sound.

Suppose the two forks *A* and *B* to be placed half the length of a wave apart, as in Figure 25. Then the wave

Fig. 25.

B A

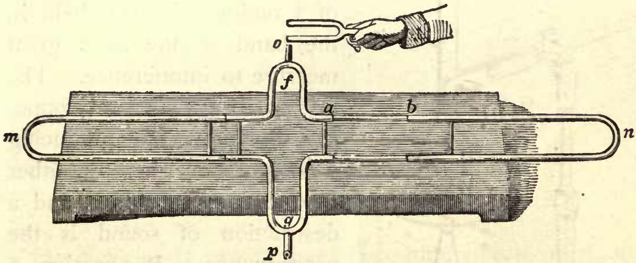


sent out by *B* will have gone twice as far as *A* whenever *A* is ready to start a wave. Hence the compression of the wave from *B* will coincide with the extension of that from *A*, and the two waves will destroy each other, so that no sound will result.

If, then, sound-waves interfere like water-waves, two sounds ought sometimes to produce silence.

In Figure 26, *o f* is a straight tube, which branches as represented, and again unites in the tube *g p*. If a tuning-fork be made to vibrate at *o*, the sound on reaching *f* will divide, a part running through the branch *m*, and a part

Fig. 26.

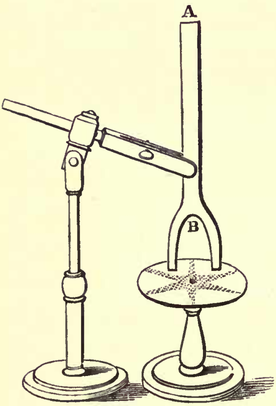


through *n*. If the two branches are of the same length, both portions of the sound will reach *p* at the same time. The branch *n* is made to slide over *a b*, so that it can be lengthened at pleasure. If *n* be made the length of half a wave longer than *m*, no sound will be heard at *p*; if it be drawn out the length of a whole wave, a sound will be heard at *p*.

This experiment shows that two sounds may produce silence.

The same fact can be illustrated by means of a vibrating disc. *A B* (Figure 27) is a *resonant* tube; that is, a tube which increases the volume of sound by sympathetic vibrations, as will be explained hereafter (57). This tube is divided at *B*. We have already learned that, when a disc is vibrating, it breaks up into parts separated by nodal lines (28), and that the parts lying side by side are vibrating in opposite directions. If then the mouths of the tube *A B* are placed over two such parts, the sound-waves will enter the tube in opposite phases, and it is found on trial that the tube does not resound. If, however, the tube is placed over *alternate* parts of the disc, which are of course vibrating in the same direction, it resounds powerfully.

Fig. 27.

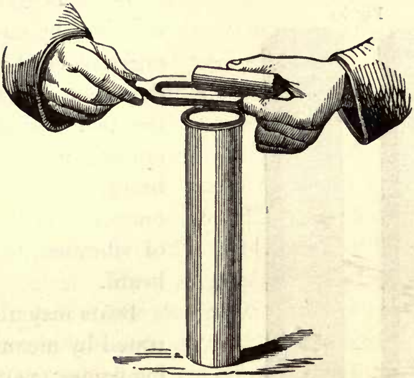


The feebleness of the sound of a tuning-fork when held in the hand is due in a great measure to interference. The prongs always vibrate in opposite directions, one producing a compression where the other produces an extension, and a destruction of sound is the consequence. By passing a pasteboard tube over one prong of the fork, its vibrations are in part intercepted, and the sound becomes louder. There are certain positions in which the sound of one prong is wholly destroyed by that of the other. These positions are easily found by making the fork vibrate, and then turning it round before the ear. When the back or the side of a prong is parallel to the ear, the sound is heard; when the corner of a prong is held toward the ear, the sound is utterly destroyed.

This case of interference may be rendered more striking by means of a resonant jar. In Figure 28 the jar is of such a length as to resound powerfully to the fork. Rotate the fork above the mouth of the jar. When the back or sides of the prongs face the jar, a loud resonance is obtained; but when the corners of the fork face the jar, there is no sound.

When the corner of the fork is over the jar, slide a pasteboard tube over one prong so as to cut off its vibrations, and the jar begins to resound.

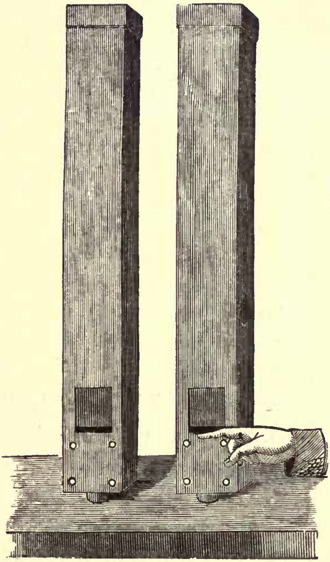
Fig. 28.



37. *Beats.* — If two tuning-forks which vibrate nearly at the same rate be made to sound together, it will be noticed that the sound, instead of being continuous, rises and falls in quick succession, producing what are called *beats*. Suppose one of the forks vibrates 240 times in a second, while hte other vibrates 246 times. The first will then make 40 vibrations while the second makes 41. The sound-waves which they generate will at first nearly coincide in the same phases; but they begin to interfere more and more, until the first has executed 20 vibrations, when they meet in opposite phases. The interference will then become less and less, until the first has made 40 vibrations, when the two sets of waves will meet again in the same phase. In this way a beat will be produced at every 40th vibration, or 6 in a second, since during the first 20 vibrations the sound is growing weaker and weaker, while during the second 20 it is growing louder and louder.

Beats are thus produced whenever two musical sounds of nearly the same pitch are uttered together, and the *number of beats per second is always equal to the difference between the two rates of vibration.*

Fig. 29.



These beats may be illustrated by means of two organ-pipes (Figure 29) of the same length. While the two are sounding in unison, if the finger be brought near the mouth of one so as to lower its rate of vibration, beats will be heard.

Beats may also be illustrated by means of sounding flames (74). Enclose two such flames in tubes provided with telescopic sliders. If the tubes are made to differ considerably in length, no beats are heard, because the notes produced are not nearly enough in unison. Gradually lengthen the shorter tube by raising the slider. At first rapid beats will be heard; but they will grow slower and slower, until the flames are brought into unison. Continue to raise the slider, and the beats are heard again, slow at first, but becoming more and more rapid, until they finally disappear.

38. *Resultant Tones.* — According to Tyndall, resultant tones may be best illustrated by means of singing flames. For this purpose use two tubes, $10\frac{5}{8}$ and $11\frac{4}{10}$ inches long. In addition to the shrill tones produced by the flames, a very deep tone may be detected. Such a tone is called a *resultant* tone, since it in some way results from the other two. On lengthening one of the tubes by means of a slider, the resultant tone gradually rises until it becomes quite distinct; on shortening the tube, it falls again.

These resultant tones may also be produced with the siren. In this case, however, as in all others, the primary notes must be forcible, or no resultant is heard. When the two series of holes numbering 8 and 12 are opened, the resultant tone has the same pitch as would be given if a series of 4 holes were open. If we open two series of 12 and 16 holes, the resultant tone is again the same as would be given by a series of 4 holes. With two series of 10 and 16 holes, the resultant is the same as would be given by a series of 6 holes. Thus, in general, it is found that *the pitch of the resultant tone answers to a rate of vibration equal to the difference of the rates of the two primaries.* From this fact these tones have been called *difference* tones.

39. *The Explanation of Resultant Tones.* — The celebrated Thomas Young thought that these resultant tones were due to the blending of rapid beats, which linked themselves together like the periodic impulses of an ordinary musical note. This explanation was in harmony with the fact that the number of the beats, like that of the vibrations of the resultant tone, is equal to the difference between the two sets of vibrations which produce the beats. This explanation, however, is insufficient. The beats tell more forcibly upon the ear than any continuous sound; for when two notes of the same intensity produce beats, the amplitude of the vibrating air-particles is at times destroyed, and at times doubled. But by doubling the amplitude we of course increase the intensity of the sound; so that beats can be plainly heard when each of the two sounds that produce them has ceased to be audible.

If, therefore, the resultant tones are due to the beats of their primaries, they ought to be heard, even when the primaries are feeble; but this is not the case. This fact led Helmholtz to investigate the subject anew. We have already seen that when several sounds traverse the same air, each particular sound passes through the air as if it alone were present, thus asserting its own individuality, and nothing more. By mathematical investigation Helmholtz found that this is in strictness true only when the amplitudes of the oscillating particles are infinitely small; but it is also practically true when the disturbances are *extremely* small. It is *not* true, however, after they have passed a certain limit. Vibrations which produce a large amount of disturbance give birth to secondary waves, and it is these which produce resultant tones. Helmholtz found further that there should be also resultant tones formed by the *sum* of the primaries, as well as by their difference. He thus discovered his *summation tones* before he had heard them; and, bringing his result to the test of experiment, he found that these summation tones have a real existence. They cannot be explained by Young's theory, but they find a complete elucidation in that of Helmholtz.

We see then that a coalescence of musical sounds is far more complicated than one would at first suppose. For instance, in the music of an orchestra, not only have we the fundamental tones of every pipe and of every string, but we have the overtones of each, sometimes audible as far as the sixteenth in the series. We have also resultant tones; both difference tones and summation tones. We have fundamental tone interfering with fundamental tone; we have overtone interfering with overtone; we have resultant tone interfering with resultant tone; and, besides all this, we have the members of each class interfering with the members of every other class. The imagination is baffled in the attempt to conceive the condition of the atmosphere through which these sounds are passing. The aim of music, through the centuries during which it has ministered to the pleasure of man, has been to arrange matters so that the ear shall not suffer from the discordance produced by this multitudinous interference. The musicians engaged in this work knew nothing of the physical facts and principles involved in their efforts; they knew no more about it than the inventors of gunpowder knew about the law of atomic proportions. They tried and tried till they obtained satisfactory results, and now, when the scientific mind is brought to bear upon the subject, these results are found to be in harmony with natural law.

SUMMARY.

A multitude of sound-waves may traverse the air without losing their character, in the same way as a multitude of water-waves may traverse the surface of the ocean.

When several sets of waves pass through water or air, the motion of every particle is the algebraic sum of the several motions impressed upon it. (34, 35.)

In the case of water, when the crests of one system of waves coincide with the crests of another system, higher waves will be the result of the coalescence of the two systems. But when the crests of one system coincide with the furrows of the other system, the two systems partially or wholly destroy each other. (34.)

The same is true of sonorous waves. If in two systems of sonorous waves compression coincides with compression, and extension with extension, the sound produced by such coincidence is louder than that produced by either system taken singly. But if the compressions of the one system coincide with the extensions of the other, a partial or total destruction of both systems is the consequence. (36.)

This mutual destruction of two systems of waves is called *interference.*

When two musical sounds of nearly the same pitch are sounded together, the flow of the sound is disturbed by *beats.* (37.)

These beats are due to the alternate coincidence and interference of the two systems of sonorous waves. If the two sounds be of the same intensity, their coincidence produces a sound of four times the intensity of either, while their interference produces absolute silence.

The effect, then, of two such sounds in combination is a series of shocks, which we have called *beats*, separated from one another by a series of *pauses*.

The rate at which the beats succeed one another is equal to the difference between the two rates of vibration. (37.)

The law of the superposition of vibrations is strictly true only when the amplitudes are exceedingly small. When the disturbance of the air by a sounding body is so violent that the law no longer holds good, secondary waves are formed. These secondary waves give rise to *resultant tones.* (38.)

Resultant tones are of two kinds, — the one class corresponding to rates of vibration equal to the difference of the rates of the two primaries; the other class corresponding to rates of vibration equal to the sum of the two primaries. The former are called *difference tones;* the latter, *summation tones.* (39.)

CHORDS AND DISCORDS.

40. *Combination of Musical Sounds.* — Take two tuning-forks, each of which gives 256 vibrations in a second, and set them vibrating. The two musical sounds flow together in a perfectly blended stream, and produce what is called *unison.* In this instance the ratio of the vibrations is 1 : 1.

Take now two forks, one of which makes 256 vibrations a second, while the other makes 512. For every wave, therefore, sent to the ear by the one fork, two waves are sent by the other, and the two notes blend harmoniously.

This combination, as we have seen, is called an *octave* (24); and the ratio of the vibrations is 1 : 2.

Take another pair of forks, which give 256 and 384 vibrations in a second. The combination of the two sounds is very pleasing to the ear, but the consonance is hardly so perfect as in the case of the octave. There is a barely perceptible roughness here, which is absent when a note and its octave are sounded; but it is too slight to render the combination disagreeable. The ratio of the vibrations is 2 : 3; that is, one of the forks sends two waves and the other three to the ear in the same interval of time. This is the most pleasing combination next to the octave, and is called a *fifth.*

If we take two forks whose vibrations are in the ratio 3 : 4, and sound them together, the interval is called a *fourth.* This combination is still agreeable, but not quite so agreeable as the fifth.

Thus, then, with perfect unison the ratio of the vibrations is 1 : 1; with a note and its octave it is 1 : 2; with a note and its fifth it is 2 : 3; and with a note and its fourth it is 3 : 4. We have thus gradually developed the remarkable law that *the combination of two notes is the more pleasing to the ear, the smaller the two numbers which express the ratio of their vibrations.*

Take now two forks whose rates of vibration are in the ratio 4 : 5, or a *major third* apart; the harmony is less perfect than in any of the cases which we have examined. With the ratio 5 : 6, or that of a *minor third*, it is usually less perfect still; and we now approach a limit beyond which a musical ear will not tolerate the combination of two sounds. If, for example, we sound together two forks whose vibrations are in the ratio of 13 : 14, their combination is altogether discordant.

An agreeable combination of two notes is called a *chord;* a disagreeable one, a *discord.*

41. *The Explanation of Chords and Discords.* — Euler's famous explanation of the nature of chords is as follows: We take delight in *order;* it is pleasant to us to observe "means co-operant to an end." But then the effort to discern order must not be so great as to weary us. If the relations to be disentangled are too complicated, though we may see the order, we cannot enjoy it. The simpler the terms in which the order expresses itself, the greater is our delight. Hence the superiority of the simpler ratios in music over the more complex ones. Consonance, then, according to Euler, was the pleasure derived from the perception of order without weariness of mind.

But in this theory it was overlooked that Pythagoras, who first experimented on these musical intervals, knew nothing about rates of vibration. It was forgotten that the vast majority of those who take delight in music, and who have the sharpest ears for the detection of a dissonance, know nothing whatever about rates or ratios. And even the scientific man who is fully informed upon these points has his pleasure in no way enhanced by his knowledge. Euler's explanation, therefore, does not satisfy the mind; and it was reserved for Helmholtz to assign the physical cause of consonance and dissonance.

Tyndall illustrates Helmholtz's explanation of consonance and dissonance by the following experiment. He converts two jets of burning gas into singing flames by enclosing them within two tubes. The tubes are of the same length, and the flames of course sing in unison. By means of a slider, he lengthens slightly one of the tubes, and gets beats which succeed one another so slowly that they can be counted with ease. He lengthens the tube still farther, and the beats become more rapid. He continues to lengthen the tube, and the beats pass into a rattle, which differs only in rapidity from the slow beats heard at first. Here we have, from first to last, nothing but an unbroken succession of beats. We begin slowly; we gradually increase the speed, until the succession is so rapid as to produce that peculiar grating effect which is called *dissonance.* If now we reverse the process, and pass from these quick beats to slow ones, the beats separate from one another more and more, until finally they are slow enough to be counted. Thus these singing flames enable us to follow the beats with certainty until they cease to be beats, and are converted into dissonance.

This experiment proves conclusively that dissonance *may* be produced by a rapid succession of beats.

Helmholtz found that beats which succeed one another at the rate of 33 per second give the greatest possible dissonance. When the beats are slower than 33, they are less disagreeable. They may even become pleasant through imitating the trills of the human voice. With higher rates than 33, the roughness also lessens, but it is still discernible when the beats number 100 a second. The limit at which they totally disappear is 132.

Does this theory accord with the facts of observation? We have found certain combinations of notes agreeable, and others disagreeable. Can this be explained on the theory of Helmholtz? We must bear in mind that musical instruments usually give overtones, and that these also interfere to produce beats. Let us start with the middle *C* of a piano, and examine its chords. The following table gives the rates of the vibrations of the fundamental tones and the first five overtones of the octave: —

		1	:	2	
Fundamental tone		264		528	Fundamental tone.
Overtones . .	1.	528		1,056	
" . .	2.	792		1,584	
" . .	3.	1,056		2,112	
" . .	4.	1,320		2,640	
" . .	5.	1,584		3,168	

Comparing these tones in couples, we find it impossible to get out of the two series a pair whose difference is less than 264. Hence, as the beats cease to be heard as dissonance when they reach 132, there can be no dissonance in this combination. This octave, therefore, is an absolutely perfect consonance.

Let us now take the interval of a fifth. We have the following fundamental tones and overtones:—

		2 :	3	
Fundamental tone		264	396	Fundamental tone.
Overtones . .	1.	528	792	
" . .	2.	792	1,188	
" . .	3.	1,056	1,584	
" . .	4.	1,320	1,980	
" . .	5.	1,584	2,376	

The lowest difference here is 132, which corresponds to the vanishing point of the dissonance. The interval of a fifth in this octave is, therefore, all but perfectly free from dissonance.

Let us now take the interval of a fourth.

		3 :	4	
Fundamental tone		264	352	Fundamental tone.
Overtones . .	1.	528	704	
" . .	2.	792	1,056	
" . .	3.	1,056	1,408	
" . .	4.	1,320	1,760	
" . .	5.	1,584	2,112	

Here we have a series of differences each equal to 88, but none lower. This number, though within the vanishing limits of the beats, is still so high as to allow very little roughness. Still the interval is clearly inferior to the fifth.

Again, let us take the major third. Here we have —

		4	:	5	
Fundamental tone		264		330	Fundamental tone.
Overtones	. . 1.	528		660	
"	. . 2.	792		990	
"	. . 3.	1,056		1,320	
"	. . 4.	1,320		1,650	
"	. . 5.	1,584		1,980	

There are here several differences, each equal to 66. The beats are nearer the maximum dissonance than in the last case, and the consonance, therefore, is less perfect.

We will now try the minor third. Here we have —

		5	:	6	
Fundamental tone		264		316.8	Fundamental tone.
Overtones	. . 1.	528		633.6	
"	. . 2.	792		950.4	
"	. . 3.	1,056		1,267.2	
"	. . 4.	1,320		1,584.0	
"	. . 5.	1,584		1,900.8	

Between several pairs of these tones we have a difference of 53 vibrations. This difference implies a greater disturbance by beats than in the case of the fifth, or of the fourth, or of the major third. Hence the minor third is inferior as a consonance to all those intervals.

Thus do we find that, as the numbers expressing the ratio of the vibrations become larger, the disturbing influence of the beats enters more and more into the interval. The result, it is manifest, entirely harmonizes with the explanation that refers dissonance to beats.

42. *The Musical Scale.* — In choosing a series of sounds for combination two by two, the simplicity alone of the ratios would lead us to fix on those expressed by the numbers $1, \frac{5}{4}, \frac{4}{3}, \frac{3}{2}, \frac{5}{3}, 2$; these being the simplest ratios that we can have within an octave. But when the notes repre-

sented by these ratios are sounded in succession, it is found that the intervals between 1 and $\frac{5}{4}$, and between $\frac{5}{3}$ and 2 are wider than the others, and require the insertion of a note in each case. The notes chosen are such as form chords, not with the fundamental tone, but with the note $\frac{3}{2}$ regarded as a fundamental tone. The ratios of these two notes with the fundamental are $\frac{9}{8}$ and $\frac{15}{8}$. Inserting these, we have the eight notes of the natural or diatonic scale expressed by the following names and ratios:—

Names.	C.	D.	E.	F.	G.	A.	B.	C'.
Intervals.	1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.
Rates of vibration.	1,	$\frac{9}{8}$,	$\frac{5}{4}$,	$\frac{4}{3}$,	$\frac{3}{2}$,	$\frac{5}{3}$,	$\frac{15}{8}$,	2.

Multiplying these ratios by 24 to avoid fractions, we obtain the following series of whole numbers, which express the relative rates of vibration of the notes of the diatonic scale.

24, 27, 30, 32, 36, 40, 45, 48.

The meaning of the terms third, fourth, fifth, &c., which we have already so often applied to the musical intervals, is now apparent; the term has reference to the position of the note in the scale.

SUMMARY.

When the combination of two notes is agreeable, they are said to form a *chord;* when their combination is disagreeable, a *discord.*

The simpler the ratio of the vibrations of two notes, the more agreeable the chord which they form. (40.)

Dissonance is due to beats.

It is greatest when the beats occur at the rate of 33 a second, and wholly disappears when they occur at the rate of 132 a second. (41.)

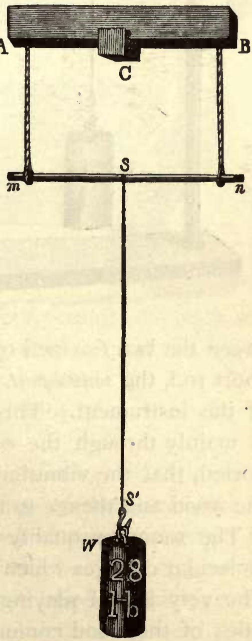
MUSICAL INSTRUMENTS.

TRANSVERSE VIBRATION OF STRINGS AND STRINGED INSTRUMENTS.

43. In many musical instruments the sounds are produced by the vibrations of strings or wires. These are called *stringed* instruments.

We proceed now to examine the laws according to which strings vibrate.

Fig. 30.



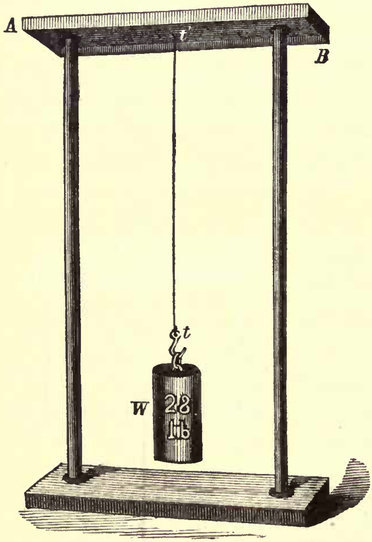
44. *A String vibrating alone gives a very feeble Sound.* — In Figure 30 *AB* is a wooden bar placed across an iron bracket *C*. *mn* is an iron bar hung from *AB* by means of ropes; and *s s'* is a steel wire which is stretched by a weight. If we take hold of the middle of the string, pull it to one side and let it go again, its elasticity will cause it to vibrate, but the sound it gives out can scarcely be heard.

If a similar string stretched by an equal weight be hung from a sounding-box *AB* (Figure 31), and be set vibrating, the sound is heard distinctly.

45. *Sounding-Boards.*—From these experiments we see that some kind of a sounding-board is necessary in all stringed instruments.

It is not the chords of a piano, or harp, or violin, that throw the air into sonorous vibrations. It is the large surfaces connected with the strings, and the air enclosed by these surfaces. The merit of such instruments depends mainly upon the quality and arrangement of their sounding-boards.

Fig. 31.



The violin, for example, is made of wood of the most perfect elasticity. The strings pass from the tail-piece of the instrument over the bridge to the pegs by which they are tightened. The two feet of the bridge rest upon the most yielding part of the body of the violin; that is, the portion between the two *f*-shaped openings. One foot is fixed over a short rod, the *sound-post*, which extends across to the back of the instrument. This foot is thereby made stiff, and it is mainly through the other foot, which is not thus supported, that the vibrations of the strings are conveyed to the wood and thence to the air within and without.

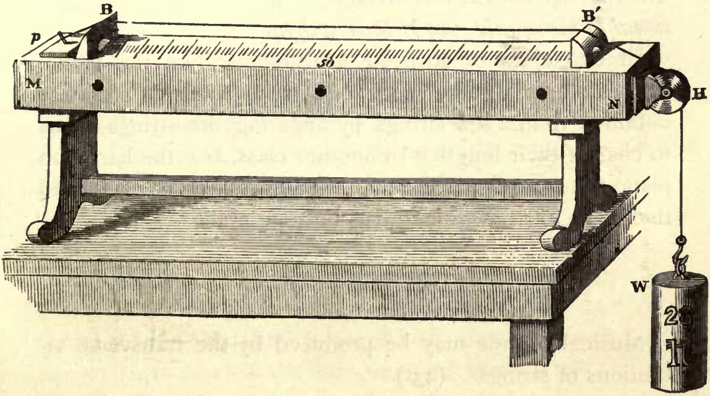
The sonorous quality of the wood is mellowed by the molecular changes which take place with the lapse of time. The very act of playing, too, appears to make the molecules of the wood conform more readily to the vibrations of the strings, and thus improves the instrument.

46. *Laws of the Vibration of Strings.* — The laws of the vibration of strings are best investigated with the sonometer, which has already been described. The first law has

already been found, and is stated thus: *The rapidity of the vibrations is inversely as the length of the string.*

47. *The Rapidity with which a String vibrates varies as the Square Root of the Weight which stretches it.* — If the string *B B′* (Figure 32) be stretched with a weight of one pound and made to vibrate, a note of a certain pitch is ob-

Fig. 32.



tained. If the weight be made four pounds, the pitch will be raised an octave; if sixteen pounds, it will be raised another octave; and so on. The rapidity of the vibrations, then, varies as the square root of the weight by which the string is stretched.

48. *The Rapidity with which a String vibrates varies inversely as its Thickness.* — If strings of the same material but of different thickness be stretched over the bridges by equal weights, the thicker strings will be found to give the lower notes. If one string is just twice as thick as another, its note will be an octave lower. In general, then, other things being equal, the rapidity of the vibrations of a string varies inversely as its thickness.

49. *The Rapidity with which a String vibrates is inversely as the Square Root of its Density.* — It is found that if a plat-

inum and an iron wire of the same length and thickness be stretched by equal weights, they will not give notes of the same pitch. The greater the density of the string, the lower the pitch of the note which it gives. It is found on trial that the pitch of the sound rises as the square root of the density diminishes.

The last two laws taken together may be stated thus: *The rapidity with which strings vibrate is inversely proportional to the square root of their weight.*

In one class of stringed instruments, like the violin, violoncello, and guitar, notes of a great variety of pitch are obtained from a few strings by fingering the strings so as to change their length. In another class, like the harp and piano-forte, many strings are used varying in length and thickness, each of which gives but one note.

SUMMARY.

Musical sounds may be produced by the transverse vibrations of strings. (43.)

The sound of a vibrating string must, however, be enforced by a sounding-board, in order to become audible. (44, 45.)

The sonometer is an instrument for investigating the laws of vibrating strings. (46.)

These laws are three in number:—

(1.) The rapidity with which a string vibrates varies inversely as its length. (46.)

(2.) The rapidity with which a string vibrates varies as the square root of the weight which stretches it. (47.)

(3.) The rapidity with which a string vibrates is inversely as the square root of its weight. (48, 49.)

In some stringed instruments many notes are produced by few strings; in others, there are as many strings as there are notes given. (49.)

LONGITUDINAL VIBRATION OF STRINGS, RODS, AND COLUMNS OF AIR; AND WIND INSTRUMENTS.

50. The vibrations of strings which we have studied thus far take place at right angles to the length of the string. A string may also vibrate in the direction of its length. This may be shown by drawing a piece of resined leather along the wire of a sonometer. It will be noticed that the sound is much shriller than when the same wire is made to vibrate transversely. In this case it is the elastic force acting among the molecules of the wire which causes it to vibrate; and, owing to the intensity of this elastic force, the vibrations are much more rapid than in the other case.

51. *The shorter the Wire, the more rapid are its Longitudinal Vibrations.* — Let one end of a long iron wire be firmly fastened to a fixed wooden sounding-box, and the other end wound round a peg, which may be turned by a key so as to stretch the wire more or less. Pass a piece of resined leather to and fro along the wire, and a musical sound is heard. Put a bridge under the middle of the wire, and rub one of its halves. The sound heard is the octave of that heard at first, showing that the vibrations are twice as rapid. Place the bridge so as to cut off one fourth of the wire, and rub that fourth. The sound produced is the octave of the last, showing that the vibrations are four times as rapid as at first.

We see, then, that the shorter the wire the more rapid its longitudinal vibrations.

52. *The Rapidity of the Longitudinal Vibrations is independent of the Tension of the String.* — Remove the bridge, so that the iron wire may vibrate throughout its entire length. Turn the key so as to change the tension of the wire, and again rub it. The pitch of the note does

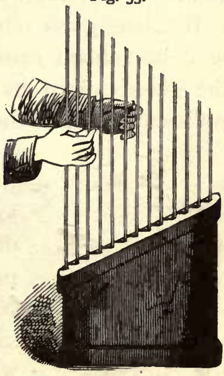
not change, showing that the rapidity of the longitudinal vibrations is independent of the tension of the wire.

53. *How to find the Comparative Velocity of Sound in Wires of Different Materials.* — If a brass wire and an iron wire of the same length and thickness be made to vibrate longitudinally, their tones are not the same,—that of the iron wire being considerably the higher of the two. In the case of these wires the sound is not produced by the wire itself, but by the sounding-box. As the wire vibrates longitudinally, its end alternately pushes and pulls upon the sounding-box, and thus throws the air within it into vibrations. This pushing and pulling is due to the passage of the sound-pulse to and fro along the whole wire. The time taken by the pulse in running the length of the wire and back is that of a complete vibration of the wire. In this time the wire gives one pull and one push to the box at its end, and one vibration to the air within it. The faster the pulse passes along the wire, the higher the note produced. If the brass wire be shortened until it gives a note of the same pitch as that given by the iron wire, it is evident that the sound-pulse traverses each of the wires in the same time. The length of the wires will be found to be in the ratio of 11 to 17, showing that sound travels only $\frac{11}{17}$ as fast in brass as in iron.

54. *The Longitudinal Vibrations of Rods free at one End.* — A smooth wooden or metallic rod with one of its ends fixed in a vise yields a musical note when rubbed with resined leather. When a rod fastened in this way yields its fundamental note (29), it simply lengthens and shortens in quick succession. When rods of different lengths are compared, the pitch of the note is found to increase as the length diminishes. By taking advantage of this fact, a musical instrument has been constructed, such as is shown in Figure 33, which produces notes of different

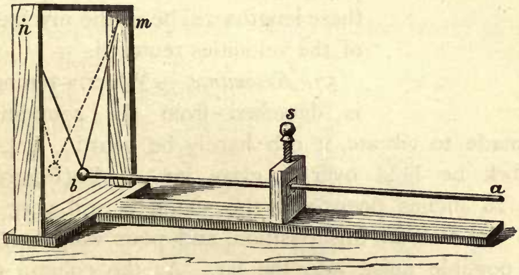
pitch by the longitudinal vibrations of wooden rods of different lengths.

Fig. 33.



55. *Longitudinal Vibrations of Rods free at both Ends.* — Clasp a long glass tube at its centre with one hand, and rub a wet cloth over one of its halves with the other. A musical sound is produced. A solid glass rod of the same length will give the same note. In this case the centre of the tube or rod is a node, and the two halves lengthen and shorten in quick succession. This lengthening and shortening of the halves of the rod is shown by the apparatus represented in Figure 34. *a b* is a brass rod held at its centre by the clamp *s*; and an ivory ball hung by two strings from the points *m* and *n* rests against the end *b* of

Fig. 34.

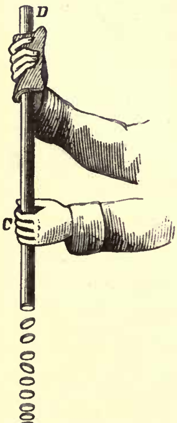


the rod. On drawing a piece of resined leather gently over the rod near *a*, it is thrown into longitudinal vibrations. The centre *s* is at rest, but the motion of the ivory ball shows that the end *b* is in a state of tremor. Rub the rod more briskly, and its vibrations become more intense.

and the ivory ball is thrown off violently whenever it comes in contact with the end of the rod.

If a long glass tube be held at the centre, and one half of it be rubbed briskly with a wet cloth, the strain upon the glass caused by the longitudinal vibrations may be sufficient to shiver the other end, as shown in Figure 35.

Fig. 35.



56. *How to find the Velocity of Sound in different Solids.* — In all cases the longitudinal vibrations of rods are produced by the passage of the sound-pulse to and fro along them. The pitch of the note given by rods of the same length depends upon the rapidity with which the pulse passes. The velocity of sound in different solids can be compared by means of rods free at both ends, as well as by means of wires. We have only to take rods of the different solids, of such lengths that they will give notes of the same pitch, and these lengths will be in the inverse ratio of the velocities required.

57. *Resonance.* — When a tuning-fork is detached from the sounding-box and made to vibrate, it can hardly be heard. Let, now, the fork be held over a glass jar *A B* (Figure 36) some 18 inches deep, and the sound is still very faint. Keep the fork in this position, and pour water with the least possible noise into the jar. As the column of air under the fork becomes shorter, the sound becomes louder ; and when the water has reached a certain level, it bursts forth with great power. Continue to pour water into the jar, and the sound becomes weaker and weaker, until it is as faint as at first. Pour the water carefully out, and we reach a point where the sound is reinforced again.

In this way we find that there is one particular length of the column of air which causes the fork above it to give

Fig. 36.

the loudest possible sound. This reinforcement of sound is called *resonance.*

By trying tuning-forks of different pitch, we find in this way a column of air for each which gives the greatest resonance. These columns are of different lengths, becoming shorter as the forks vibrate faster.

Fig. 37.

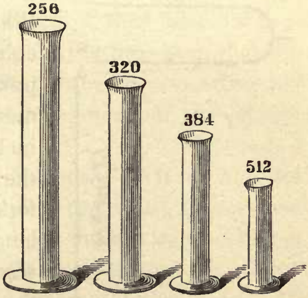
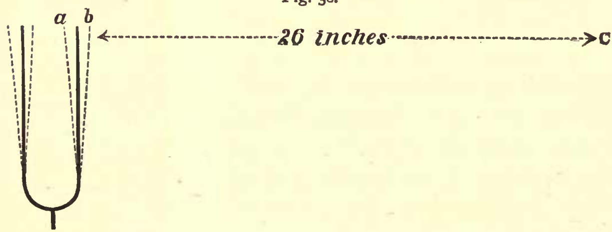


Figure 37 shows the relative lengths of jars which give the greatest resonance for tuning-forks vibrating 256, 320, 384, and 512 times in a second.

58. *The Length of the Column of Air which resounds to a vibrating Fork is equal to one fourth the Length of the Wave produced by the Fork.*—The greater volume of sound when the fork is vibrating over a resonant jar can be due only to the greater amount of motion communicated to the air. When is the fork enabled thus to increase the motion?

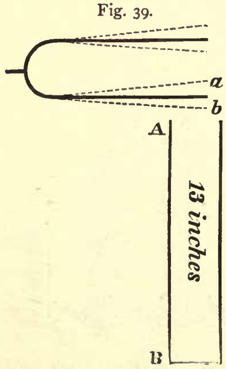
We have seen that a fork vibrating 256 times a second produces a sound-wave 4 feet 4 inches long (23). In Figure 38, suppose a prong of the fork to be vibrating between

Fig. 38.



the points *a* and *b*. In going from *a* to *b*, the prong generates half a sound-wave; and when it reaches *b*, the foremost point of the wave will be at *c*, 2 feet 2 inches from the fork. What then is the length of the column of air which resounds most powerfully for this fork? By measurement we find it to be 13 inches. But the whole length of the sound-wave produced by the fork is 52 inches. Hence the length of the column of air which resounds for this fork is one fourth the length of the sound-wave produced by the fork. We find the same to be true in the case of every fork.

Fig. 39.



59. *Cause of Resonance.* — Suppose now the prong of the fork to be vibrating over the jar *A B* (Figure 39). While the prong is moving from *a* to *b*, the compression which it produces runs to the bottom of the jar, where it is reflected; and as the distance down and back is 26 inches, the reflected wave will reach the fork just as it is on the point of returning from *b* to *a*. The extension of the wave is caused by the retreat of the prong from *b* to *a*, and will also run to the bottom of the jar and back in time to overtake the prong just as it reaches the point *a*. If now the prong were to remain at *a*, the molecules of air on reaching it would rebound, and thus produce a compression of the air in the jar; but just as they are ready to rebound, the prong begins to move downward, and gives them a push. Now, as this push is given every time just as they are about to rebound, it adds more and more to their motion; much in the same way as a heavy ball hung by a string may be made to swing through a great distance by a succession of very slight pushes, provided they are so timed as to act upon the ball just as it is ready to retreat. If the pushes are not thus timed, they are as likely to check the motion as to increase it. So in the case of the resonant jar; the vibrations of the column of air would be as likely to be checked as increased, if they were not synchronous with those of the fork. It is thus seen that the vibrations of the fork are perfectly *synchronous* with (that is, take place in the same time with) those of the column of air *A B*.

60. *Savart's Illustration of Resonance.* — If a bow be drawn across the edge of a bell (Figure 40), it gives out a musical sound. If now the open mouth of a cylinder closed at the other end be brought near one of the vibrating parts of the bell, the sound is greatly reinforced. If the cylinder be alternately removed and brought near, the sound sinks and swells in a striking manner. If it be

allowed to sink until it cannot be heard, and the cylinder be again brought near, the sound becomes audible again.

Fig. 40.

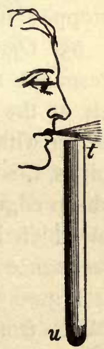
61. *Further Facts concerning Resonance.* — "The resonance of caves and of rocky enclosures is well known. Bunsen notices the thunder-like sound produced when one of the steam jets of Iceland breaks out near the mouth of a cavern. Most travellers in Switzerland have noticed the deafening sound produced by the fall of the Reuss at the Devil's Bridge. The noise of the fall is raised by resonance to the intensity of thunder. The sound heard when a hollow shell is placed close to the ear is a case of resonance. Children think they hear in it the sound of the sea. The noise is really due to the reinforcement of the feeble sounds with which even the stillest air is pervaded. By using tubes of different lengths, the variation of the resonance with the length of the tube may be noticed. The channel of the ear itself is also a resonant cavity. When a poker is held by two strings, and when the fingers of the hands holding the poker are thrust into the ears, on striking the poker against a piece of wood a sound is

heard as deep and sonorous as that of a cathedral bell. When open, the channel of the ear resounds to notes whose periods of vibration are about 3,000 per second. This has been shown by Helmholtz; and a German lady named Seiler has found that dogs which howl to music are particularly sensitive to the same notes." (Tyndall.)

62. *A Column of Air may be made to vibrate by blowing across the End of a Tube.*—Select two jars, and two tuning-forks which will cause them to resound. Cause both forks to vibrate, and hold them both over one of the jars. Only one of them is heard. Hold them both over the other jar, and the other fork alone is heard. Each jar selects that fork for reinforcement whose vibrations are synchronous with its own. Instead of two forks, two dozen might be held over either of these jars, and from the medley of pulses thus generated the jar would select and reinforce the one which corresponds to its own period of vibration.

Blow now across the open mouth of this same jar, or across the mouth of a glass tube of the same length as the jar, and $\frac{3}{4}$ of an inch in diameter (Figure 41). A fluttering of the air is thus produced; in fact, a medley of pulses is generated at the mouth of the tube. The tube selects the pulse which is synchronous with its own vibration, and reinforces it so that it becomes a musical sound. The sound is the same as that produced by the proper tuning-fork held over the tube. The column of air in the tube has, in fact, made its own tuning-fork; for, by the reaction of its pulses, it has made the air blown across the tube vibrate in unison with itself.

Fig. 41.



On blowing across the mouth of a tube of any length, a musical sound is produced exactly like that obtained when the proper tuning-fork is held over the tube.

63. *The Rate of Vibration of a Column of Air in a Tube is inversely proportional to its Length.* — Take three tubes 6, 12, and 24 inches long. Blow gently across the mouth of each tube so as to bring out its fundamental note. The note of the 12-inch tube will be the octave of the note of the 24-inch tube, and that of the 6-inch tube the octave of that of the 12-inch tube. This must be the case; for, since the rate of vibration depends upon the distance the pulse must travel to complete a vibration, the greater this distance the slower the vibration. In other words, the rate of vibration is inversely proportional to the length of the tube through which the pulse passes.

64. *Vibrations in Open Tubes.* — The tubes which have been used thus far have been closed at one end. Such tubes are called *stopped* tubes. We will next examine the vibrations of tubes open at both ends, or *open* tubes. If we take a stopped tube and an open tube of the same length, and blow gently across the mouth of each so as to get its fundamental note, we shall find the note of the latter an octave higher than that of the former. An open tube always yields the octave of the note given by a stopped tube of the same length.

65. *Organ-Pipes.* — Organ-pipes are nothing more than resonant tubes. There are various ways of agitating the air at the mouth of such tubes, so as to set the columns of air within them into vibrations. In one kind of organ-pipes, this is done by blowing a thin sheet of air against a sharp edge. This produces a flutter, some particular pulse of which is then converted into a musical sound by the resonance of the air in the tube.

Figure 42 represents an *open* organ-pipe. The air passes from the bellows through the tube *P* into a chamber, which is closed at the top except the narrow slit *i*. The air compressed in the chamber passes through this slit in a thin sheet which breaks against the sharp edge *a*, and there produces a flutter. The space between the edge *a* and the slit below is called the *mouth* of the pipe.

Fig. 42.

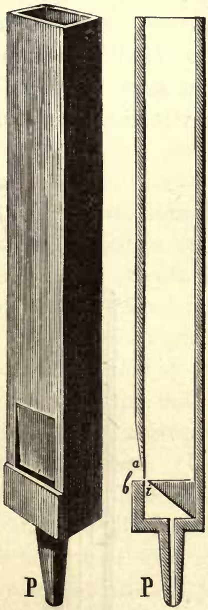


Fig. 43.

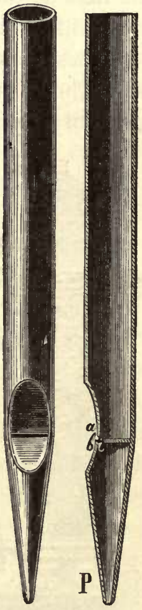


Figure 43 represents a *stopped* organ-pipe, so called because its upper end is closed. Instead of producing a flutter at the mouth of the pipe by a blast of air, we may get the same effect by holding at the mouth of the pipe (Figure 44) a tuning-fork whose vibrations are synchronous with those of the pipe. Select several pipes of different lengths, and tuning-forks which vibrate in unison with each. Beginning with the longest pipe, make the fork of lowest pitch vibrate near its mouth. The pipe *speaks* powerfully. Blow into the same pipe; its tone is exactly the same as when the fork was held at its mouth. Try each of the pipes in the same way, and the note which each gives when blown into is exactly that given when the proper fork is at its mouth. If all the forks are held at the same time at the mouth of any one of the pipes, their vibrations will produce pulses of very different period. Out of all these, however, the pipe will select and reinforce but one. The result would be the same if several hundred forks of different pitch were vibrating at the mouth

Fig. 44.

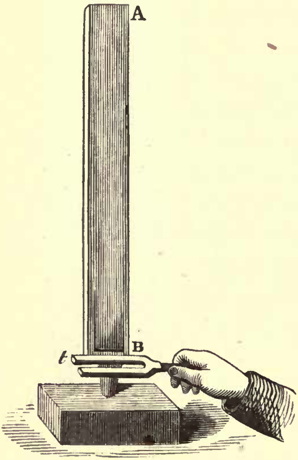


Fig. 45.

of the pipe. So also the current of air striking against the sharp upper edge of the mouth of the pipe gives rise to a great variety of pulses, from which the pipe selects and reinforces but one.

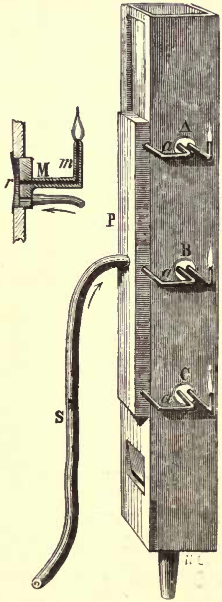
66. *The Condition of the Air within an Organ-Pipe examined by means of a Membrane.* — The front of the organ-pipe in Figure 45 is of glass, so that we can see the position of any body within. If now the pipe be made to

speak, and a thin membrane stretched upon a light frame be let down into it by a string, on entering the pipe the membrane begins to give a rattling sound. This continues until it reaches the centre, when it ceases to sound. On passing below the centre, it again begins to rattle. It is made to rattle above and below the centre by means of the particles of air which are there vibrating against it. The fact that it is silent at the centre of the pipe shows that the particles of air are there at rest. The centre of the column of air in the open pipe is then a *node*. Such a column of air vibrates like a rod free at both ends (55). There is no vibration at the centre, but alternate compression and extension, while at the ends there is little change of density but the maximum of vibration.

67. *The Condition of the Air in an Organ-Pipe examined by means of Gas-jets.* — If a sounding pipe were pierced at the centre, and the hole stopped by an elastic membrane, the air when compressed at this point would push the membrane outward. On the other hand, when the air within was extended, the outer air would press the membrane inward. The membrane would thus be made to vibrate in unison with the column of air. If holes were made near the ends of the pipe and stopped in a similar manner, the membranes would not vibrate, since the air at these points is not undergoing changes of density.

By means then of a pipe pierced in this way we can ascertain experimentally whether the air within the pipe is undergoing changes of density at the centre and not at the ends. Figure 46 represents a pipe arranged for this experiment. The pipe is pierced at the points *A*, *B*, and *C*, and the holes are closed by elastic membranes. Over each membrane is a little chamber which is filled with gas by means of the pipe *S*. Projecting from each chamber is a small bent burner. Light the three burners and blow into the pipe. All the flames are agitated, but the centre one much the most. Turn down the gas so that the flames may be very small, and blow into the pipe again. The centre flame will be blown out, the others will still burn. It is evident, then, that the membrane at the centre vibrates much more strongly than the others.

Fig. 46.



68. *Why an Open Pipe gives the Octave of a Stopped Pipe of the same Length.* — When a column of air is vibrating in a pipe closed at one end, the closed end is evidently a node, for the molecules of air near it have no chance to vibrate. In the case of an open pipe, the node is at the centre, and the parts of the air vibrating are only half the length of the pipe. Hence they will vibrate twice as rapidly as the column of air in the stopped pipe, if the pipes are of the same length.

69. *How to find the Relative Velocity of Sound in Different Gases.* — We have seen (58) that the length of a resonant jar is one fourth that of the sound-wave which it produces; therefore the length of a stopped organ-pipe will be one fourth the length of its sound-wave, and the length of an open pipe one half that of its sound-wave.

If a jar which resounds to a tuning-fork be inverted and filled with hydrogen, it will no longer resound to this fork; but if a jar four times as long be filled with hydrogen, it will resound to this fork. But the sound-wave must run to the bottom of the jar and back while the fork is performing one half a vibration (59). Hence the wave must travel four times as fast in hydrogen as in air.

Now organ-pipes can be made to speak by blowing other gases than air through them, and we can accordingly find the relative velocity of sound in different gases by finding the length of the organ-pipe which must be used with each in order to give a note of the same pitch.

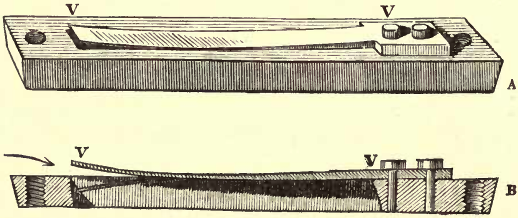
70. *How to find the Relative Velocity of Sound in Different Liquids.* — By forcing liquids through properly constructed organ-pipes they may be made to speak, just as when gases are forced through them. By using different liquids and finding a series of pipes which give the same note with each, we can determine the relative velocity of sound in those liquids. Thus, if a solution of common salt is forced through one pipe and alcohol through another, it will be found that the latter pipe must be about three times as long as the former, in order to give the same note; showing that the velocity of sound in alcohol is about three times as great as in a solution of salt.

71. *How to find the Actual Velocity of Sound in Different Substances.* — We have now learned how to find the relative velocity of sound in different solids, liquids, and gases, and the actual velocity of sound in air. How can we find its actual velocity in other substances than air? We evidently can find its velocity in other gases by multiplying its velocity in air by its relative velocity in the gases. To find its actual velocity in liquids, we must first know its velocity in some one liquid compared with its velocity in air. The velocity of sound in water may be compared with its velocity in air by forcing water and air through organ-pipes. It is thus found that water requires a pipe a little more than four feet long to give the same note that air will give in a pipe one foot long; showing that the velocity of sound in water is a little more than four times its velocity in air. After having found its velocity in water, its velocity in other liquids may be found by multiplying its velocity in water by its relative velocity in these liquids.

The velocity of sound in any solid, as pine wood, may be compared with its velocity in air by finding the length of a rod of pine which yields the same note as an organ-pipe. It is thus found that the rod must be ten times as long as the pipe, — showing that the velocity of sound in pine is ten times its velocity in air. The velocity of sound in other solids may be found by multiplying its velocity in pine wood by its relative velocity in those solids.

72. *Reed Pipes.* — A column of air may be made to vibrate by means of a spring of metal or wood, called a *reed.* The metal reed commonly used in organ-pipes is shown in Figure 47. It consists of a long and flexible

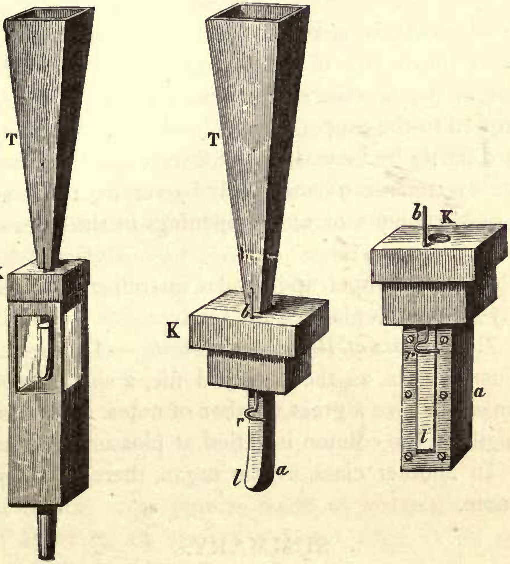
Fig. 47.



strip of metal, *V V*, placed in a rectangular opening through which the current of air enters the pipe. As soon as the air begins to enter the pipe, the force of the blast bends down the spring of the reed so as to close the opening. The elasticity of the reed causes it to fly back at once, so as to open the pipe and allow the air to enter again. It thus breaks up the current of air into a regular succession of little puffs.

The way in which the reed and the pipe are connected is shown in Figure 48. The reed is placed within the chamber *K*, into which air is forced through the tube at the bottom. *T* is a conical pipe of metal, the opening of which is covered by the reed, as already explained. The wire *b r* is used to lengthen or shorten the reed, and thus to vary its rate of vibration.

Fig. 48.



When the vibrations of the reed and the pipe are exactly synchronous, the sound is most pure and forcible. If their rates of vibration vary beyond a certain limit, the pipe ceases to be of any use, and the reed vibrates alone. Unless, however, the reed is quite stiff, the column of air compels it to vibrate in unison with itself. This may be illustrated by means of a common straw. With a pen-

Fig. 49.

knife raise a strip of the straw near a knot, as shown at *r r′* in Figure 49. This strip serves as a reed, and the straw as a pipe. Blow into it, and it gives a musical note. Make it shorter and shorter, and the note rises higher and higher. Here the reed remains the same, but is compelled to make its vibrations synchronous with those of the varying column of air.

The clarionet is a reed pipe. It has a single broad tongue at the mouth of a long cylindrical tube. By the pressure of the lips the slit between the reed and its frame is narrowed to the proper extent. The different notes are obtained partly by increasing the force of the blast so as to produce overtones (29), and partly by varying the length of the resonant column of air by openings in the sides of the tube.

In the horn, trumpet, and similar instruments, the lips of the player take the place of the reed.

73. *Two Classes of Wind Instruments.* — In one class of wind instruments, as the flute and fife, a single column of air is made to give a great number of notes. In this case the length of the column is varied at pleasure by means of keys. In another class, as the organ, there is a pipe for every note.

SUMMARY.

Wires and rods may vibrate longitudinally as well as transversely. (50.)

Longitudinal vibrations are much more rapid then transverse vibrations, and increase in rapidity as the rods diminish in length. (51.)

These vibrations may be illustrated by means of rods free at one end or at both ends. (54, 55.)

The velocity of sound in different solids may be compared by causing rods of those solids to vibrate longitudinally. The velocity of sound in different solids is inversely proportional to the length of the rods which give notes of the same pitch. (56.)

The sound of a tuning-fork is reinforced when it vibrates over the mouth of a jar of air of a certain depth. The depth of the jar is different for forks of different pitch. This reinforcement of sound is called *resonance.* (57.)

The length of a column of air which reinforces the sound most is equal to one fourth the length of the wave produced by the fork. (58.)

The vibrations of a resonant column of air are synchronous with those of the sounding body. It is this synchronism which causes the motion of the particles of the air to accumulate so as to produce the resonance. (59.)

Jars and tubes may be made resonant by blowing across their open mouths, and give the same note as when made to resound by a tuning-fork. (62.)

The shorter the column of air, the faster it vibrates. (63.)

An open tube gives a note which is the octave of a closed tube of the same length. (64.)

Organ-pipes are resonant tubes. When open at both ends, they are called *open* pipes ; when closed at one end, *stopped* pipes.

One kind of organ-pipe is made to resound by blowing a thin sheet of air against a sharp edge at its mouth. (65.)

The condition of the air within an organ-pipe may be examined by means of a stretched membrane, or by means of gas-jets.

When an open pipe is giving its fundamental note, the centre is a node, and the column of air is vibrating in the same way as a rod free at both ends. At the centre of the column there is the minimum of vibration, and the maximum of change in density ; while at the ends there is the maximum of vibration, and the minimum of change in density. (66, 67.)

In a stopped pipe the end is a node, so that such a pipe is equivalent to an open pipe of twice the length. (68.)

The length of a stopped pipe is one fourth that of the sound-wave which it produces; while that of an open pipe is one half that of the sound-wave it produces.

The velocities of sound in different gases, liquids, and solids may be determined from the lengths of these substances which give notes of the same pitch. (69, 70, 71.)

A column of air may be made to vibrate by means of a *reed.*

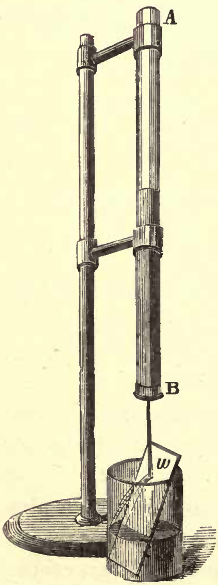
When the reed is limber, it is compelled to vibrate in unison with the column of air in the pipe with which it is connected; when it is stiff, its rate of vibration is but little affected by the resonance of the air in the pipe.

The clarionet and many other wind instruments are reed-pipes. (72.)

There are two classes of wind instruments. (73.)

SOUNDING FLAMES.

Fig. 50.



74. *Friction always Rhythmic.* — When we draw a bow across a string, or rub a wet finger round the edge of a glass, a musical sound is produced, showing that the friction has been broken up into rhythmic pulses. Close the lower end of the tube *A B* (Figure 50) with a metallic plate, pierced by a round hole whose diameter is equal to the thickness of the plate. Plug the hole, and fill the tube with water. Remove the plug, and, as the water sinks in the tube, a very sweet musical note is given out by the liquid column. This note is due to the intermittent flow of the water through the hole, by which the column above is thrown into vibrations. The same intermit-

tence is observed in the dense smoke which rolls in rhythmic rings from the funnel of a steamboat. The noise produced by the friction of machinery is due to the alternate "bite" and release of the rubbing surfaces.

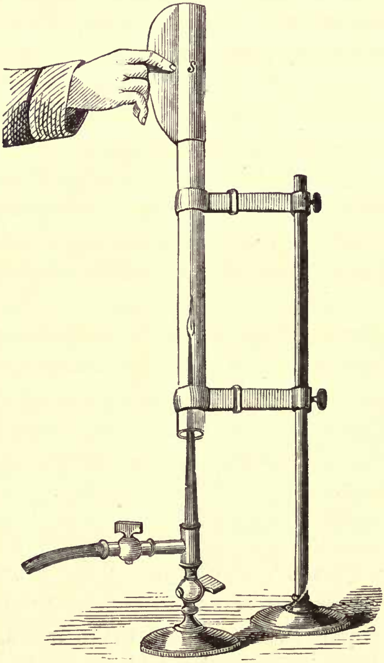
The friction of gases is of the same intermittent character. A rifle-ball sings as it passes through the air. "The whispering pines" owe their music to the rubbing of the wind against their branches and foliage. The whistling of the wind is also produced by the rhythmic friction of the air.

If we blow gently against a candle-flame, the fluttering noise announces a rhythmic action. We have already learned (65) that, when a pipe is associated with a flutter, it selects from it a special pulse, and raises it by resonance to a musical sound. In like manner, the noise of a flame may be converted into a musical note. The special pulse first selected soon reacts upon the flame so as to destroy, in a great degree, the other pulses, and compels the flame to vibrate in unison with itself.

When a gas-flame is simply enclosed in a tube, the passage of the air over it is usually sufficient to produce the necessary rhythmic action, and to make it sing. With a tube 15 feet long and 4 inches wide, and a large Bunsen's burner, Professor Tyndall produced a sound powerful enough to shake the floor and seats, and the large audience that occupied the seats, of his lecture-room.

75. *The Pitch of the Note given by a Sounding Flame depends upon the Length of the Tube.* — In Figure 51 we have a glass tube held over a gas-jet. By means of the paper slider *s*, this tube may be lengthened or shortened. While the flame is sounding, raise the slider and the pitch falls; lower the slider, and the pitch rises. By the reaction of the pulses reflected upon the flame, its flutter is made periodic, the length of the period being determined, as in the case of organ-pipes, by the length of the tube.

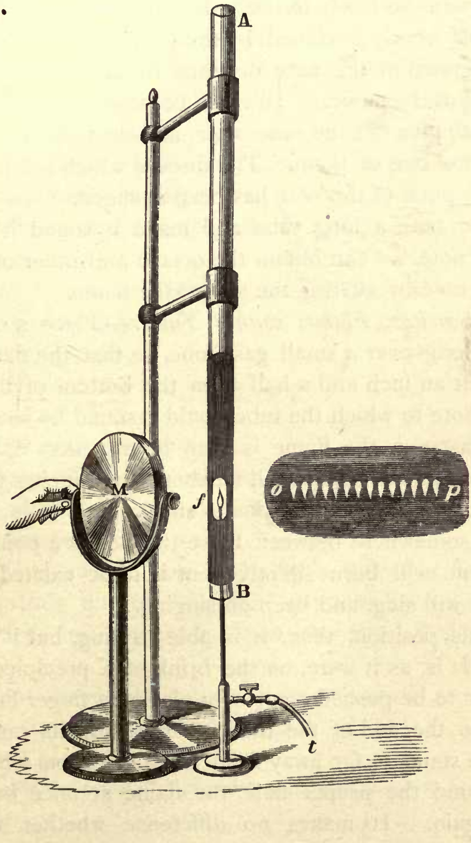
Fig. 51.



76. *In a Sounding Flame the Gas is alternately extinguished and relighted.* — In Figure 52, *A B* is a glass tube 6 feet long and 2 inches wide. The lower part of the tube is blackened, except a small place at *f*. *M* is a concave mirror, which forms upon a screen an enlarged image of the flame. By turning the mirror, the image may be made to pass over the screen. On twirling the mirror, we obtain a series of images *o p*. If the lower end be partially closed with the hand, so as to stop the vibration of the flame, we get a continuous band of light when the mirror is twirled. If we remove the hand again, this band instantly breaks up into a beaded line of images.

In this way Professor Tyndall has found that the spaces between the images of a singing flame are absolutely dark. If so, the flame must be extinguished and relighted at reg-

Fig. 52.



ular intervals. By means of a siren, the rate at which a singing flame vibrates, and the rapidity with which it is put out and lighted again, may be determined. Professor

Tyndall found that a flame with which he was experimenting was thus put out and relighted 453 times in a second.

77. *The Pitch of the Note produced by a Sounding Flame depends somewhat on the Size of the Flame.* — A singing flame yields so freely to the pulses that fall upon it, that it is almost wholly governed by the tube which surrounds it; but the pitch of the note depends in some measure upon the size of the flame. This can be proved by causing two flames to give out the same note, and then slightly altering the size of one of them. The discord which results shows that the pitch of the note has been changed.

If we take a long tube and make it sound its fundamental note, we can obtain the octave and other overtones of that note by altering the size of the flame.

78. *Sensitive Flames within Tubes.* — Place a tube 12 inches long over a small gas-flame, so that the flame shall be about an inch and a half from the bottom of the tube. If the note to which the tube would resound be sounded at some distance, the flame is seen to tremble. Lower the tube, so that the flame shall be about three inches from the bottom, and the flame begins to sing. Now it is possible to find somewhere between these two points a point where the flame will burn silently; but if it be excited by the voice it will sing, and keep on singing.

In this position, then, it is able to sing, but it needs a start. It is, as it were, on the brink of a precipice, but it requires to be pushed over. By placing a finger for an instant on the end of the tube, we can stop its music. If now we stand as far away from it as the room will allow, and sound the proper note, the flame at once begins to sing again. It makes no difference whether we face the flame or stand with the back towards it, — whether we sound the note with the voice or with any musical instrument.

Let there be two small flames, *a* and *b*, some way apart, with a tube over *a* about 10 inches long, and one over *b* about 12 inches long. A paper slider is fitted to the shorter tube so that its length may be varied. Arrange the tubes so that the flame in *a* shall sing while that in *b* is silent. If now we raise the paper slider which surrounds *a* so as to lengthen the tube, when the pitch of this tube comes near enough to that of the other the flame *b* begins to sing. The experiment may be varied by making *b* the singing flame, and *a* the silent one at starting. On drawing up the slider a point will soon be reached where the flame *a* will begin to sing.

This shows that a singing flame may cause a silent one to begin to sing.

Flames which are thus affected by musical sounds are called *sensitive* flames.

SUMMARY.

Friction is always rhythmic.

When a gas-flame is surrounded by a tube, the air in passing over it is thrown into vibrations, and musical sounds are produced. (74.)

The pitch of the note given by a sounding flame depends mainly on the length of the tube by which it is surrounded, but somewhat upon the size of the flame. (75, 77.)

A silent flame within a tube may be made to sing by sounding the note of the tube near it. (78.)

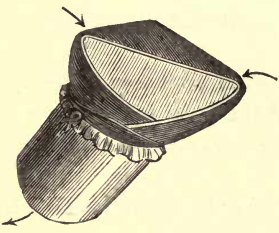
NOTE. For an account of sensitive *naked* flames see Appendix, II.

THE HUMAN VOICE.

79. *The Organ of Voice a Reed Instrument.* — The organ of voice in man is situated at the top of the windpipe, or *trachea*, which is the tube through which the air is blown from the lungs. A pair of elastic bands, called *the vocal chords*, stretched across the top of the windpipe so as nearly to close it, form a double reed. When the air is forced from the lungs through the slit between these chords, they are made to vibrate. By changes in their tension their rate of vibration is varied, and the sound raised or lowered in pitch. The cavity of the mouth and nose acts as a resonant tube.

The action of the vocal chords may be imitated by means of india-rubber bands. If the open end of a glass tube be closed by two strips of india-rubber, leaving a slit between them, and the air be blown through this slit, the strips are thrown into vibration, and a musical sound is produced. Helmholtz recommends the form shown in Figure 53, where the tube, instead of being cut off square, ends in two oblique sections, over which the rubber bands are stretched.

Fig. 53.



The easiest way of making such a reed is to wrap round the end of a glass tube a strip of thin india-rubber, leaving about an inch of the substance projecting beyond the end of the tube. Take two opposite portions of the projecting rubber in the fingers, and stretch them, so as to form a slit. On blowing through this slit a musical sound is produced which varies in pitch as the sides of the slit vary in tension.

80. *Vowel Sounds.* — We can readily distinguish one vowel sound from another, even when both are of the same pitch and intensity. What then is the real difference between them?

Fix a reed in a frame without any pipe connected with it. Force air through it with a bellows, and it speaks forcibly. Fix now upon the frame a pyramidal pipe, and the clang-tint changes at once. Push the flat hand over the open end of the pipe, and sounds are produced very much like those of the human voice. If we close the end of the pipe entirely with the palm of the hand, and then raise the hand twice in quick succession, the word "mamma" is distinctly uttered. If the same experiment be repeated with a shorter pyramidal tube, the word "mamma" is given as it would be uttered by a child with a stopped nose. Thus, by connecting a suitable pipe with a vibrating reed, we can give to the sound of the reed the qualities of the human voice.

Now, in the vocal organ of man we have the reed in the vocal chords, and, connected with this, the resonant cavity of the mouth, which can so alter its shape as to resound either to the fundamental tone of the vocal chords, or to any of their overtones. By means of the mouth, then, we can mix together the fundamental tone and the overtones of the voice in different proportions, and the different vowel sounds are the result. The cavity of the mouth may be made to resound by means of tuning-forks; and it is found that when it is adjusted so as to resound to a certain fork, only one particular vowel sound can be produced by forcing air from the lungs across the vocal chords. If the cavity is adjusted so as to resound to a fork of different pitch, only one vowel sound can be produced, but it is different from the one obtained before; and so on. In all these cases, if the vowels are uttered with the same pitch and intensity, the condition of the vocal chords is not changed. They give throughout the same fundamental tone and the same overtones; and the different vowel sounds obtained are due solely to the fact that, in the different cases, different tones have been reinforced by the resonance of the mouth.

Retaining the same fundamental tone, by adding other tones, or by varying the intensity of the fundamental tone or of one or more of the overtones, we can alter the quality of the clang (30), and thus produce the different clang-tints of the human voice.

SUMMARY.

The vocal organ in man is a reed instrument, the vibrating reed being a pair of elastic bands at the top of the windpipe, which are capable of different degrees of tension. (30.)

By connecting suitable pipes with reeds, we can give to their tones the qualities of the human voice.

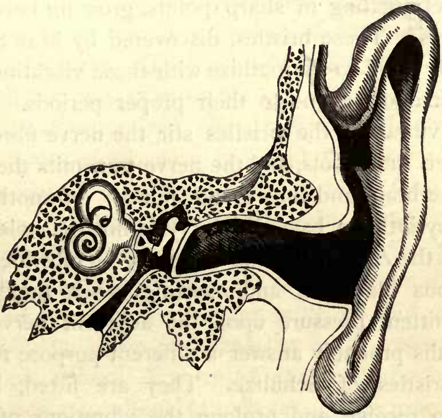
The rate of vibration of the vocal chords is but little affected by the resonance of the mouth; but the mouth, by changing its shape, can be made to resound to the fundamental tone, or to any of the overtones of the vocal chords. By strengthening particular tones through the resonance of the mouth, we can change the clang-tint of the voice.

The different vowel sounds result from different mixtures of the fundamental tone and the overtones of the vocal chords. (80.)

THE HUMAN EAR.

81. A section of the human ear is shown in Figure 54. In this organ we have, first of all, the external opening of the ear, which is closed at the bottom by a circular membrane called the *tympanum*. Behind this is the cavity

Fig. 54.



called the *drum* of the ear. This cavity is separated from the space between it and the brain by a bony partition, in which there are two openings, the one round and the other oval. These also are closed by delicate membranes. Across the cavity of the drum stretches a series of four little bones: the first, called the *hammer*, is attached to the tympanum; the second, called the *anvil*, is connected by a joint with the hammer; a third little round bone connects the anvil with the *stirrup bone*, which has its oval base planted against the membrane of the oval opening, almost covering it. Behind the bony partition, and between it and the brain, we have the extraordinary organ called the *labyrinth*, which is filled with water, and over the lining of which the fibres of the auditory nerve are distributed. The tympanum intercepts the vibrations of the air in the external ear, and transmits them through the series of bones in the drum to the membrane which separates the drum from the labyrinth ; and thence to the liquid within the labyrinth itself, which in turn transmits them to the nerves. The transmission is not, however, direct. At a certain place within the labyrinth, exceedingly fine elastic bristles, terminating in sharp points, grow up between the nerve fibres. These bristles, discovered by Max Schultze, are exactly fitted to sympathize with those vibrations of the water which correspond to their proper periods. Thrown thus into vibration, the bristles stir the nerve fibres which lie between their roots, and the nerve transmits the impression to the brain and thus to the mind. At another place in the labyrinth we have little crystalline particles called *otoliths*,—the *Hörsteine* of the Germans,—embedded among the nervous filaments, and exerting, when they vibrate, an intermittent pressure upon the adjacent nerve fibres. The otoliths probably answer a different purpose from that of the bristles of Schultze. They are fitted, by their weight, to receive and prolong the vibrations of evanescent sounds, which might otherwise escape attention. The bristles of Schultze, on the contrary, because of their extreme lightness, would instantly yield up an evanescent motion, while they are peculiarly fitted for the transmission of continuous vibrations. Finally, there is in the labyrinth a wonderful organ, discovered by Corti, which is to all appearance a musical instrument, with its chords so stretched as to receive vibrations of different periods and transmit them to the nerve filaments which traverse the organ. Within the ear of man, and without his knowledge or contrivance, this lute of 3,000 strings * has existed

* According to Kölliker, this is the number of fibres in Corti's organ.

for ages, receiving the music of the outer world, and rendering it fit for reception by the brain. Each musical tremor which falls upon this organ selects from its tense fibres the one appropriate to its own pitch, and throws that fibre into sympathetic vibration. And thus, no matter how complicated the motion of the external air may be, these microscopic strings can analyze it, and reveal the elements of which it is composed.

Such are the views now entertained by the most eminent authorities as to the transmission of sonorous motion to the auditory nerve. They are not to be considered as established, but only as probable.

82. *The Range of the Human Ear.* — We have already seen that vibrations cease to blend into one sound when they are very slow. Helmholtz has found that there must be at least 16 vibrations in a second in order that they may be heard as a continuous sound. Depretz has shown that the sound ceases to be audible when the vibrations reach 38,000 in a second. Starting with 16 and multiplying continually by 2, we find that the 11th octave will have 32,768 vibrations. The entire range of the human ear, then, extends to about 11 octaves. The practical range of musical sounds is from 40 to 4,000 vibrations in a second, or about 7 octaves.

The limits of hearing are different in different persons. Dr. Wollaston, to whom we owe the first proof of this, found that one of his friends could not hear the sound of a small organ-pipe, the sharpness of which was far within the ordinary limits of hearing. The squeak of the bat, the sound of a cricket, even the chirrup of the English house-sparrow, are unheard by some people who possess a sensitive ear for lower sounds. The ascent of a single note is sometimes sufficient to produce the change from sound to silence. "The suddenness of the transition," writes Wollaston, "from perfect hearing to total want of perception, occasions a degree of surprise which renders an experiment of this kind with a series of small pipes among several persons rather amusing. It is curious to observe the change of feeling manifested by various individuals of the party, in succession, as the sounds approach and pass the limits of their hearing. Those who enjoy a temporary triumph are often compelled, in their turn, to acknowledge to how short a distance their little superiority extends." "Nothing can be more surprising," writes Sir John Herschel, in reference to this subject, "than to see two persons, neither of them deaf, the one complaining of the penetrating shrillness of a sound, while the other maintains there is no sound at all. Thus, while one person mentioned by Dr. Wollaston could but just hear a note 4 octaves above the middle E of the pianoforte, others have a distinct perception of sounds full 2 octaves higher. The chirrup of the sparrow is about the former limit; the cry of the bat about an octave above it; and that of some insects probably another octave." In "The Glaciers of the Alps" Professor Tyndall relates that while crossing the Wengern Alp he found that a friend who was with him could not hear the shrill music of the swarms of insects in the grass on the sides of the path, though to himself the sound seemed to rend the air.

It may be remarked that the shrill notes of many insects are the result of the rapid vibrations of their wings, amounting sometimes to more than 16,000 in a second.

SUMMARY.

The human ear consists of three parts: the outer ear, the drum, and the labyrinth.

The sonorous vibrations are first intercepted by the tympanum, then transmitted to the fluid in the labyrinth, and then again intercepted by the bristles of Schultze, the otoliths, and the fibres of Corti, by which they are communicated to the auditory nerve. (81.)

The range of human hearing embraces about eleven octaves. (82.)

CONCLUSION.

Sound originates in a vibrating body, and is transmitted through air and other elastic media by means of waves, with a velocity which increases with the ratio of the elasticity to the density. Its velocity in air at the freezing-point is 1,090 feet a second. When sound-waves meet a medium different from that in which they are moving, they are partially reflected and partially transmitted. In the reflected portion the angle of reflection is always equal to the angle of incidence. The transmitted portion is refracted, either away from or towards a perpendicular to the surface of the new medium, according as the velocity of sound is greater or less in this medium than in the old.

Bodies which vibrate regularly and with sufficient rapidity produce musical sounds. The pitch of the sound increases with the rapidity of the vibrations; and the intensity, with the amplitude of the vibrations. All sounding bodies are capable of originating vibrations of several different periods at the same time, and the blending of these vibrations produces the *quality* or *clang-tint* of the sound. Sonorous bodies are capable of taking up from the air and other elastic media those vibrations which are synchronous with their own, and in this way they are thrown into sympathetic vibrations.

In passing through the air different sound-waves may coincide so as to increase their volume, or else interfere so as partially or wholly to destroy one another. When meeting in alternating phases, sound-waves give rise to *beats*, and, if of sufficient volume, to *resultant* tones. Dissonance is caused by a rapid succession of beats.

The rapidity of the transverse vibrations of strings depends upon their length, their tension, and their weight. By varying these we can produce a regular succession of musical sounds, as in stringed instruments.

The rapidity of the longitudinal vibrations of rods varies with their length and elasticity. By means of such vibrating rods we can measure the velocity of sound in different solids. A column of air can be thrown into longitudinal vibrations by a tuning-fork, by a fluttering current at the mouth of the tube which contains the column, and by a reed. The rapidity of the vibrations depends upon the length of the column. By causing columns of gases and liquids to vibrate, we can measure the velocity of sound in each. In wind instruments musical sounds are produced by means of vibrating columns of air. In singing flames the column of air is made to vibrate by the fluttering of the flame.

The human organ of voice is a reed instrument, and the different vowel sounds are produced by altering the resonant cavity of the mouth and nose, so as to cause it to reinforce different overtones of the vocal chords.

The human ear is an apparatus for intercepting the vibrations of the external air and transmitting them to the auditory nerve.

II.

LIGHT.

NATURE AND PROPAGATION OF LIGHT.

RADIATION.

83. A body in which light is developed is called a *luminous* body. All other bodies are said to be *non-luminous.*

84. *A Luminous Body sends out Light in Every Direction.* — It is well known that, if a lighted lamp is placed in the middle of a room, it illumines every part of the room; showing that the light proceeds from the luminous body in every direction.

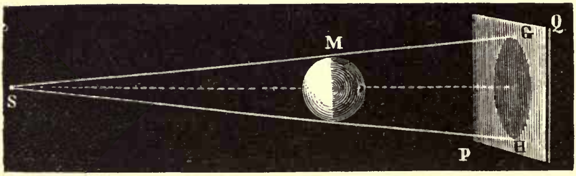
A body through which light passes, as air and glass, is said to be *transparent.* Other bodies are said to be *opaque.*

85. *Light travels through Space in Straight Lines.* — If a room be darkened, and the sunlight be allowed to enter through a small hole in the shutter, it will illumine the floating particles of dust in the air through which it passes, so that we can trace its path; and in every case we find that it moves in a straight line. It is for this reason that we cannot see an object when there is any opaque body between it and the eye.

When an opaque body is placed before a luminous one, it cuts off the light from the space behind it, producing what is called a *shadow.*

If the luminous body S (Figure 55) is a mere point, the body M will cast a well-defined shadow $G H$ upon the screen *P Q*. If the straight line *S G* be carried round the sphere *M*, touching it all the time, the part *M G* will ex-

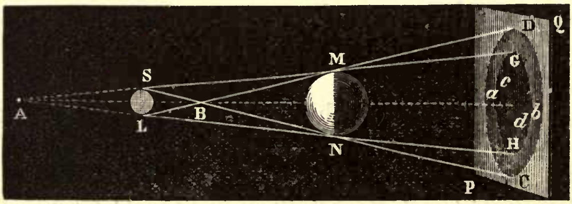
Fig. 55.



actly mark the limits of the shadow cast by *M*. The form of this shadow, then, shows that light moves through the air in straight lines.

If the luminous body is not a mere point, then the shadow cast by the sphere *M N* (Figure 56) will have an

Fig. 56.

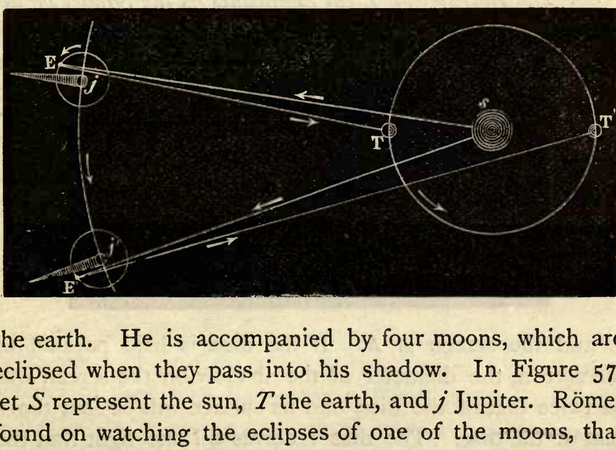


indistinct outline. The reason of this is evident. If the line *S G* be carried round, touching both spheres all the time, the portion *M G* will mark out the space within which no ray of light from *S L* can enter. Around this space there will be a space from which a part of the light of *S L* is cut off. This extends to the outer circle *D C;* for it is evident that light from *S* can pass into the space between *D* and *G*, while it is cut off from the space between *C* and *H;* and light from *L* can pass into the space between *C* and *H*, while it is cut off from that between *D* and *G*. As we proceed from the outer ring *D C* to the inner one *G H*, more and more of the light from *S L* is cut off, so that the shadow, instead of being sharply defined, fades gradually into the light. The dark central portion *G H* of the shadow is called the *umbra;* the less dark outer portion is called the *penumbra.* *Umbra* is the Latin word for *shadow*, while *penumbra* means *almost a shadow.*

86. *Rays.* — Since a luminous body gives out light in every direction in straight lines, it is said to *radiate* light. A single line of light is called a *ray.* A collection of rays is called a *pencil.* If the rays are parallel, it is a *parallel* pencil, or a *beam;* if the rays diverge, it is a *divergent* pencil; if they converge, a *convergent* pencil.

87. *The Velocity of Light.* — Light moves so fast that it seems to require no time at all to pass over any distance on the earth. Its velocity was first determined by Römer, a Danish astronomer, in 1675, by observing the eclipses of Jupiter's moons. Jupiter, like the earth, is a planet which revolves about the sun, but at a much greater distance than

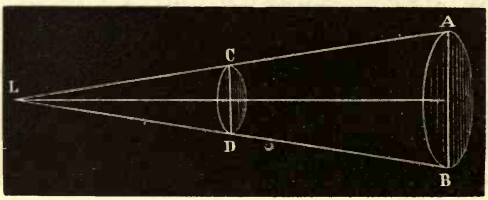
Fig. 57.



the earth. He is accompanied by four moons, which are eclipsed when they pass into his shadow. In Figure 57, let *S* represent the sun, *T* the earth, and *j* Jupiter. Römer found on watching the eclipses of one of the moons, that while the earth was moving from *T* to *T'*, the intervals between the eclipses grew longer and longer; and that while the earth was passing from T' round to T again, they became shorter and shorter; while they should have remained constantly the same. Now it is evident that we should not be aware of the eclipse until the light which left the moon just as it entered the shadow had reached us; and that as the earth passes from T to T' the distance which this light must travel is continually increasing, while as the earth passes from T' to T this distance is continually decreasing. If, then, light requires time to pass over this distance, the interval between the eclipses should lengthen in the one case and shorten in the other. Römer found that the increase in the intervals while the earth was passing from T to T' amounted to 16 minutes; that is, the eclipses at T' occurred 16 minutes later than they would have occurred had the earth remained at T. He therefore concluded that it takes light about 16 minutes to cross the earth's orbit, a distance of about 190,000,000 miles. Its velocity then would be about 192,000 miles a second.

88. *The Intensity of Light diminishes as the Square of the Distance from the Luminous Body increases.* — In Figure 58 the disc $C\ D$ is held half-way between the luminous point

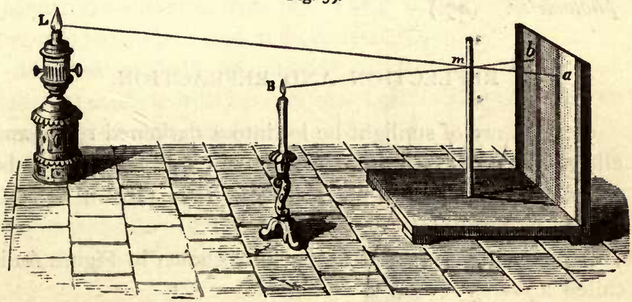
Fig. 58.



L and the screen $A\ B$. If the disc is held parallel to the screen, the diameter of the shadow on the screen will be twice that of the disc, and its surface will be four times that of the disc. The disc receives all the light that the space covered by the shadow would receive if the disc were removed. The light on the disc must then be four times as intense as that upon the screen. If the disc is held one third of the way between *L* and the screen, the shadow will cover a surface nine times that of the disc, and the intensity of the light on the disc will be nine times as great as that upon the screen; and so on. The intensity of the light, then, diminishes as the square of the distance increases.

89. *Photometers.* — An instrument for measuring the relative intensity of lights is called a *photometer.* One of the simplest is that of Count Rumford, shown in Figure 59. An opaque rod *m* is placed in front of a ground-

Fig. 59.



glass screen. The lights to be compared, as *L* and *B*, are placed in such a way that each casts the shadow of the rod upon the screen. Their distances are then made such that the two shadows *a* and *b* are of exactly the same intensity. The screen must, then, be receiving the same amount of light from *L* and *B*; for the shadow cast by *B* is illumined by *L*, and that cast by *L* is illumined by *B*. To find now the intensity of the light from the two sources, measure the distance of each from the screen. These distances are to each other as the square roots of the intensities of the lights; and the intensities of the lights are to each other as the squares of the distances.

SUMMARY.

A luminous body gives out light in every direction, which passes through space in straight lines. (84, 85.)

A single line of light is called a *ray*, and a collection of rays, a *beam*, or *pencil*. (86.)

Light traverses space with a velocity of about 190,000 miles a second. (87.)

The intensity of light diminishes as the square of the distance increases. (88.)

The intensity of light is measured by means of the *photometer*. (89.)

REFLECTION AND REFRACTION.

90. If a ray of sunlight be let into a darkened room, and allowed to fall upon a looking-glass, it will be seen to be thrown back from the glass. Light thus thrown back is said to be *reflected*.

A piece of glass cut into the form shown in Figure 60 is called a *prism*.

Fig. 60.

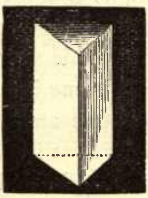
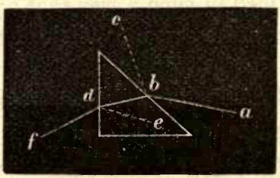


Fig. 61.



If a ray of light, *a b*, be allowed to fall obliquely upon one side of such a prism, as shown in Figure 61, a part of the light is seen to be reflected in the direction *b c*, and another part, *b d*, to enter the prism. It will be seen that the part which enters the prism is bent from the direction of the original ray. When this part meets the air at the opposite side of the prism, a part of it is again reflected in the direction *d e*, and a part passes into the air, taking a different direction, *d f*, from that which it had while in the prism.

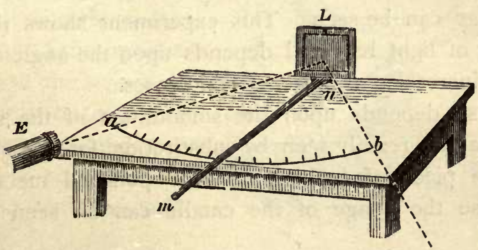
We see, then, that when light travelling in the air meets the glass, it is partly reflected and partly transmitted; and that when light travelling in the glass meets the air again, it is also partly reflected and partly transmitted. In both cases the transmitted portion is turned aside from its course. Light thus turned aside is said to be *refracted.*

It is found that, in general, when light meets a transparent medium different from that which it has been traversing, it is partly reflected and partly refracted.

If a ray of light be allowed to fall upon a piece of polished steel, it will be seen that light is also reflected on meeting with an opaque body.

91. *The Law of Reflection.* — In Figure 62, we have a

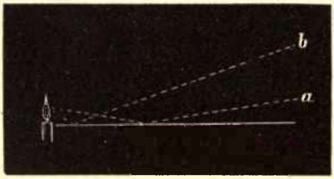
Fig. 62.



plane mirror *L* fastened at right angles to the rod *m n*, and turning upon a pivot at *n*. As the mirror is turned to the right or left, the rod passes over the graduated arc *a b*. If a ray of light be allowed to fall upon the mirror in the direction of the dotted line *a n*, it will be reflected in the direction of the line *n b;* and it will be seen that the angle *a n m* is equal to the angle *b n m*. The former is called the *angle of incidence*, and the latter the *angle of reflection*. Both the incident and reflected rays lie in the same plane with the perpendicular. If the mirror be turned, the direction of the reflected ray changes in such a way that *the angle of incidence always equals the angle of reflection*. This is always true of reflected light, and is known as the *law of reflection*.

92. *The Intensity of Reflected Light.* — It is by light thus reflected that we see an object in a mirror or other smooth surface. If we hold a sheet of writing-paper horizontally and close to the flame of a lamp or candle (Figure 63), and put the eye close down to the paper, as at *a*, so as to receive the light which is reflected very obliquely, a distinct image of the flame will be seen on the paper. If the eye be placed higher up, as at *b*, so as to receive the light reflected less obliquely, no image can be seen. This experiment shows that the amount of light reflected depends upon the angle of incidence, increasing as this angle increases.

Fig. 63.



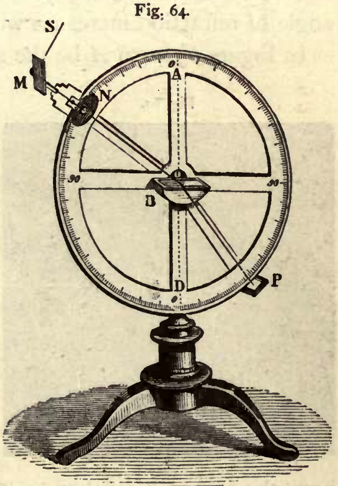
It also depends upon the smoothness of the surface. This may be readily seen by substituting for the sheet of paper a piece of looking-glass or polished metal. In this case the image of the candle can be seen at any angle.

The reflection is found to vary somewhat with different substances, even when the degree of polish and the angle of incidence are the same.

It is well known that non-luminous bodies are not visible in the dark, but become visible when light falls upon them. It is evident, then, that they must send to our eyes some of the light they receive. This light must be sent out in every direction, since we can see them as well from one position as another. The light which they thus throw off is said to be *diffused*. It is this diffused light which enables us to see the body itself; while reflected light enables us to see another body in it. The most perfectly polished mirror does not reflect all the light it receives. It diffuses a portion, so that we see the mirror as well as the objects reflected in it.

93. *The Law of Refraction.* — The bending of a ray of light in passing from one medium to another can be illustrated by the apparatus shown in Figure 64. *A D* is a graduated circle; *B*, a semi-cylindrical glass vessel filled with water just up to the centre of the circle. *O M* and *O P* are two arms, each of which turns about the centre of the circle. One carries a mirror *M*, so arranged as to throw the ray of light *S* through the opening of the screen *N* upon the surface of the water exactly at the centre of the circle. The other arm carries a small screen *P*.

Fig. 64.

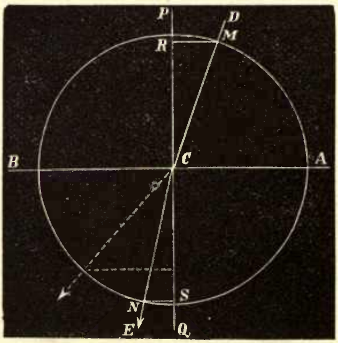


In order that the refracted ray may fall upon this screen, we find that the arm *O P* must be placed so as to make the angle *D O P*, or the *angle of refraction*, less than the angle *A O M*, or the *angle of incidence*, showing that when a ray of light passes from air into water it is bent towards a perpendicular drawn to the surface of the water. This is found to be always true when the light passes from a rarer to a denser medium. When it passes from a denser to a rarer medium, it is bent away from a perpendicular drawn to the surface of the latter medium. For instance, if the mirror M be carried round to P, so that the light passes from P to O, it will be found that on passing into the air again it takes the direction $O M$. It is evident, then, that on passing from water into air it is bent away from the perpendicular just as much as it is bent towards it on passing into water.

Suppose the mirror M to be moved either towards or away from A; the screen P will have to be moved, in order to receive the refracted ray. In this way we find that the angle of refraction increases with the angle of incidence.

In Figure 65 let $B A$ be the surface of a denser medium; $P Q$, a perpendicular to that surface; $D C P$, the angle of incidence of the ray $D C$; $E C Q$ its angle of refraction; and $M N$ a circle described about C as a centre. On changing the angle of incidence, it is found that the angle of refraction changes in such a way that the lines $M R$ and $N S$, drawn perpendicular to $P Q$, always have the same ratio; that is, if, for any value of the angle of incidence, $M R$ is twice as long as $N S$, it will be twice as long for every value. These lines are called the *sines* of the angles $D C P$ and $N C S$, and the law of refraction may be thus stated: *When light passes from one medium into another, the ratio which the sine of the angle of incidence bears to the sine of the angle of refraction is always the same for the same media.*

Fig. 65.



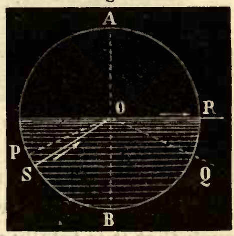
It is found, however, that this ratio varies with different media.

Of course, when the incident ray is perpendicular to the surface of the new medium, no refraction takes place.

94. *Index of Refraction.* — The ratio between the sines of the angles of incidence and refraction is called the *index of refraction.* This index varies with the media. For example, from air to water it is $\frac{4}{3}$; from air to glass $\frac{3}{2}$; and so on. Of course, from water to air, it will be $\frac{3}{4}$; from glass to air $\frac{2}{3}$; and so on.

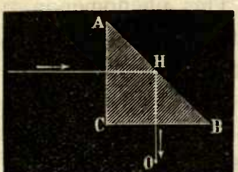
95. *Total Reflection.* — When a ray of light passes from a denser to a rarer medium, as from water into air, the angle of refraction is, as we have seen, greater than the angle of incidence. Hence when light passes through water from *S* to *O* (Figure 66) there is always a value of the angle of incidence *S O B* such that the angle of refraction *A O R* is a right angle. In this case the ray cannot pass from the water into the air. If the incident angle be made any larger, the light is thrown back in the direction of *Q*. In this case it is said to be *totally reflected.*

Fig. 66.



This total reflection may be illustrated by means of a prism whose section is an isosceles right angled triangle. It will be seen that none of the light (Figure 67) can get through the prism, but it is all reflected in the direction *H O.*

Fig. 67.

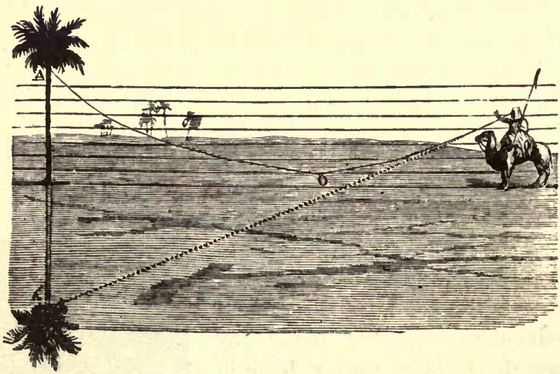


The angle at which light in passing from water to air begins to be totally reflected is 48° 35′; from glass to air, 41° 48′. *

* See Appendix, III.

96. *Mirage.* — In hot climates, especially on the sandy plains of Sahara in Africa, the ground has often the appearance of a tranquil lake, on which are seen reflected houses and trees. This is caused by total reflection. The layers of air near the ground are more heated, and therefore less dense than those higher up. A ray of light, then, coming from *A* (Figure 68) is bent round more and more

Fig. 68.



as it passes down through the successive layers until it reaches the point *O*, where the angle of incidence becomes such that it is totally reflected, and reaches the eye as if it came from *A′*. The same will be true of light coming from other parts of the tree, so that the tree will appear inverted, as if reflected in water. This phenomenon is called *mirage*, and often deludes the thirsty traveller on the desert with the appearance of water which vanishes as he draws near it.

Another form of mirage, the reverse of this, is often seen on the water. In this case the layers of air near the water are colder and more dense than those above, so that the rays of light passing upward from an object are bent round more and more, until at last they are totally reflected downward to the eye of the observer, who thus sees the object inverted in the air.

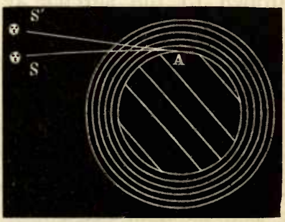
97. *Some of the Effects of Refraction.* — Suppose a body to be at *L* (Figure 69) beneath the surface of water. The rays of light coming from it on reaching the surface are refracted in the directions *A C* and *B D*, so that they appear to come from the point *L′*. Now as we see an object in the direction in which the light from it reaches the eye, the object *L* will appear to be at *L′*, or higher up than it really is. This explains why it is that a stick placed obliquely in the water appears bent, as in Figure 70. Each part of the stick in the water appears to be lifted up a little by refraction.

Fig. 69.

Fig. 70.

In the same way light is refracted in passing through the air, and since the air is more and more dense as it is nearer the earth, a ray of light is bent more and more as it approaches the earth. Hence we see the sun and the stars before they rise and after they set. It will be evident from Figure 71 why it is that we always see a heavenly body higher up than it really is.

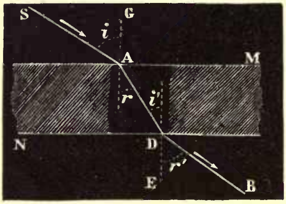
Fig. 71.



Refraction varies with the condition of the atmosphere. Sometimes at sea it is so great that objects below the horizon, as ships and islands, are lifted up enough to become visible. Occasionally we have this extraordinary effect of refraction combined with mirage, so that a ship which is really below the horizon may be seen suspended in the air with its inverted image beneath it.

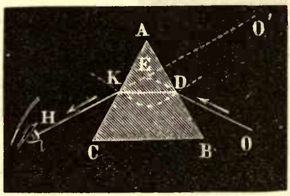
98. *Path of Rays through a Medium with Parallel Faces.* — When light passes through a medium with parallel faces, the rays leave this medium at the same angle at which they entered it. In Figure 72 let *M N* be a plate of glass with parallel faces. *i* is the angle of incidence of the ray *S A*, and *r* the angle of refraction: *i'* is the angle of incidence of the same ray when it meets the air again, and *r'* the angle of refraction. Since the ray in passing into the air is bent away from the perpendicular just as much as it was bent towards it in passing into the glass, the angle *r'* will evidently be equal to the angle *i*; that is, the ray leaves the glass at the same angle at which it entered it. Its direction, therefore, after leaving it is the same as before entering it.

Fig. 72.



99. *Path of Rays through a Prism.* — In Figure 73 let *A B C* be the section of a prism. The ray of light *O D* on passing into the prism is bent towards a perpendicular drawn to the surface at *D*. On passing out into the air again it is bent away from a perpendicular drawn to the surface at *K*. We see, then, that a ray of light in passing through a prism is bent twice in the same direction, unless it meets one of the faces perpendicularly.

Fig. 73.



SUMMARY.

When light falls on a transparent medium different from that in which it is moving, it is partially reflected and partially refracted. (90.)

The angle of reflection equals the angle of incidence. (91.)

The amount of light reflected depends upon the angle of incidence, the polish of the surface, and the nature of the medium.

All bodies diffuse light, and it is by means of this diffused light that we see them.

Light is also reflected from opaque surfaces. (92.)

The ratio of the sine of the angle of incidence to that of the angle of refraction always remains the same for the same medium, but is different for different media. This ratio is called the *index* of refraction. (93, 94.)

On meeting a rarer medium at a certain angle, light is totally reflected. (95.)

Mirage and other atmospheric phenomena of the kind are caused by irregular refraction. (96.)

On passing through a medium with parallel sides, a ray of light emerges parallel to its original direction. (98.)

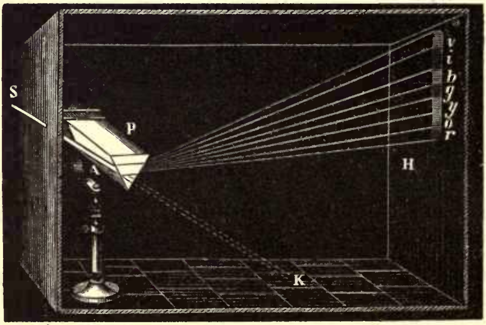
On passing through a prism, a ray is bent twice in the same direction. (99.)

DISPERSION.

100. *The Solar Spectrum.* — Allow a beam of sunlight, *S A* (Figure 74) to pass through a small opening into a darkened room, and fall upon the prism *P*. If the prism be placed at the proper angle, the beam of light is not only bent from its course, but is spread out so as to form a long band of light on the opposite wall. This band is not white,

like ordinary sunlight, but made up of the seven colors of the rainbow, *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*. This colored band is called the *solar spectrum*.

Fig. 74.



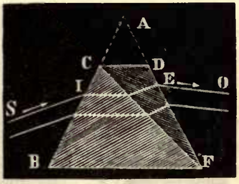
When prisms of different substances are used, the spectra obtained have the same colors and in the same order, but are of different lengths.

This spreading out of a beam of light is called *dispersion;* and the power of any substance to produce this effect is called its *dispersive power*. We might think that the dispersive power of a substance would be in proportion to its refractive power, but this is not the case. Thus the refractive power of flint glass is almost the same as that of crown glass, but its dispersive power is nearly double. The liquid known as bisulphide of carbon has great dispersive power; hence it is often used for prisms. When a liquid is used in this way, it is enclosed in a hollow glass prism.

In order to obtain a spectrum in which the colors are distinctly seen, the opening through which the light enters should be very narrow, and if the refracting angle of the prism is, as usual, 60°, the screen on which the spectrum is received must be 5 or 6 yards distant.

101. *Achromatic Prism.* — By combining a flint-glass prism *C D F*, (Figure 75), with a crown-glass prism *C B F*, the dispersive power of the latter may be neutralized, without wholly neutralizing its refractive power. The reason of this will be evident from the figure. The prism *C D F*, in order to have the same dispersive power as *C B F*, needs be only half as thick as the latter; so that the edges *B C* and *F D* are still inclined as though they were sides of the larger prism *A B F*.

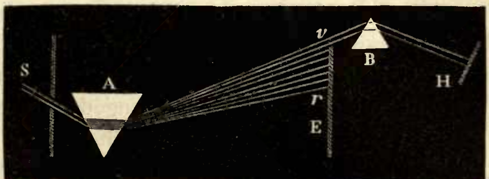
Fig. 75.



Such a combination of prisms forms what is called an *achromatic* (*colorless*) prism.

102. *The Prismatic Colors are Simple.* — If all the colors of the spectrum except one be cut off by a screen, and that one be allowed to fall on a second prism, as shown in Figure 76, it will be again refracted, but will not be separated into different colors. Hence the colors of the spectrum are said to be *simple*.

Fig. 76.

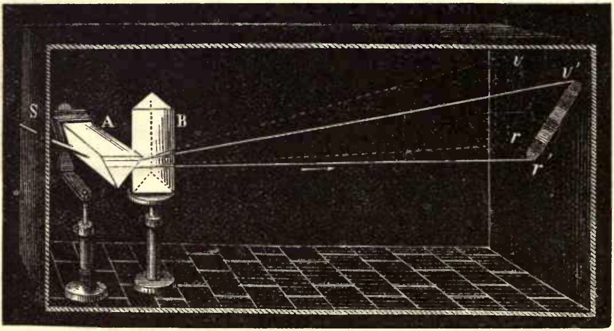


103. *The Prismatic Colors are unequally Refrangible.* — The position of the colors in the spectrum shows that they are not equally refracted. The red is least, and the violet most refracted.

That the colors are unequally refrangible may be shown by the following experiment. If the beam of light *S*,

(Figure 77,) after passing through the horizontal prism *A*, be allowed to fall on the upright prism *B*, it forms the

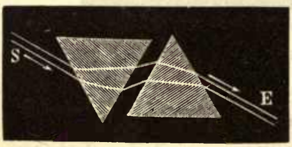
Fig. 77.



oblique spectrum $v' r'$, proving that from red to violet the colors are more and more refrangible.

104. *The Composition of White Light.* — These experiments with the prism seem to show that white light is not simple, but made up of the seven prismatic colors. This view is confirmed by the fact that white light can be produced by the blending of these seven colors. If the spectrum produced by one prism be allowed to fall upon a second prism exactly like the first, arranged as shown in Figure 78, the latter brings together again the rays which have been dispersed by the former, and white light is the result.

Fig. 78.



The same may be shown by mixing these colors in the eye. This can be done by painting them in the proper proportions upon a circular disc (Figure 79) and making this disc rotate rapidly, as shown in Figure 80. The impression of each color remains in the eye during a complete rotation of the disc, so that the seven are blended into one, and the disc appears white.

Fig. 79.

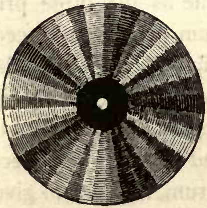
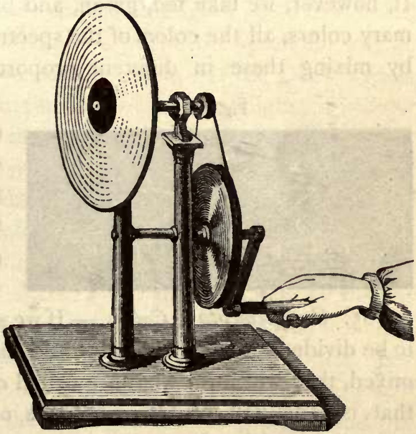
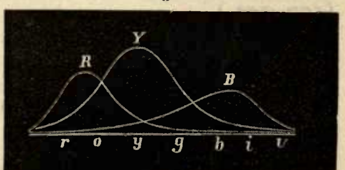


Fig. 80.



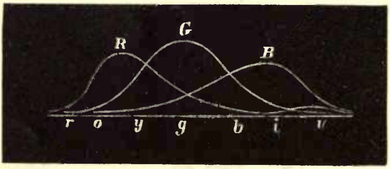
White light, or something which ordinary eyes cannot distinguish from it, may also be produced by the blending of a part of the prismatic colors. Thus red, yellow, and blue, or red, green, and blue, will form white. This fact has led some to suppose that the solar spectrum is made up of but three simple colors. Brewster chose red, yellow, and blue. He assumed that each one of these colors extended the whole length of the spectrum, as shown in Figure 81. The height of the curve shows the intensity of each color in different parts of the spectrum. On this theory the orange is produced by a mixture of the red and yellow; the green by a mixture of the yellow and blue; and so on.

Fig. 81.



But it has been shown by Maxwell and Helmholtz that "the direct mixture of the prismatic yellow and blue, in whatever proportion, can nohow be made to produce green." If, however, we take red, green, and blue as the three primary colors, all the colors of the spectrum can be produced by mixing these in different proportions. The way in which these three colors must be distributed through the spectrum, in order to give the seven prismatic colors, is shown in Figure 82.

Fig. 82.



105. *Complementary Colors.*—If we suppose the spectrum to be divided into any two parts, and the colors in each part mixed, they will form what are called *complementary* colors; that is, one will contain what the other needs to make white light. We often call colors *complementary* when their mixture would approach more or less nearly to white.

SUMMARY.

In passing through a prism a beam of white light is dispersed, and forms a spectrum of seven colors. Different substances disperse light differently. Hence two prisms may be combined so as to form an *achromatic* prism. (100, 101.)

Prismatic colors are simple and unequally refrangible. (102, 103.)

The blending of the seven prismatic colors produces white light.

It is possible to form the solar spectrum out of the three simple colors, red, green, and blue. (104.)

Two colors whose mixture will produce white light are said to be *complementary*. (105.)

ABSORPTION.

106. If light be made to pass through a piece of colored glass, and then to fall upon a prism, the spectrum will be found to be wanting in certain colors. If red glass is used, the spectrum will contain little besides red light; if blue or green glass is used, the spectrum will be rich in blue or green, and deficient in other colors. A part of the light, then, is retained in the glass, and is said to be *absorbed* by it. In this way all colored transparent bodies are found to absorb a portion of the light which falls upon them.

107. *The Color of Bodies.* — Opaque bodies, as well as transparent ones, absorb light. This explains why it is that, when white light is falling upon non-luminous bodies, they do not all appear of the same color. They are really *sifting* the light which they receive, absorbing a part and diffusing or transmitting the rest. Their color depends upon the light which they reflect, and this is of course the complement of that which they absorb. Thus a body which absorbs all the prismatic colors except red appears red; one which absorbs all except green appears green; and so on. A painter does not *add* color to his canvas, but *destroys* a part of its color; that is, he causes it to absorb a part of the white light which falls upon it, and to reflect only the remainder, instead of reflecting it all. His direct action is upon the tint *complementary* to that which he aims to produce.

It sometimes happens that bodies *transmit* a color different from that which they *reflect*, and such bodies appear of a different color according as they are seen by transmitted or reflected light. This is the case with gold, which appears yellow by reflected light, and green by transmitted light, as may be seen by holding a piece of gold leaf between the eye and the sunshine.

108. *The Analysis of Colors.* — The colors of objects may be analyzed by means of a prism. Take a very narrow strip of the object, a mere line of colored light, and place it upon a perfectly black ground and in a very strong light. Examine this strip through a prism, whose edge is held parallel with it, and it appears dilated into a spectrum, which has only rays of those colors which combine to form its tint.

A cheap and convenient instrument for this analysis may be made by fastening a metal plate, having in it a sharply cut and very narrow slit, to one end of a tube of metal or pasteboard, about an inch square and 12 or 14 inches long, and blackened within. A small prism of colorless flint glass is fixed within the other end parallel with the slit, so that when the tube is directed to a white cloud, the slit shall be seen dilated into a clear prismatic spectrum The object to be examined must be placed so near the slit as to allow no other rays to enter than come from some part of its surface, and must be strongly illuminated either by direct sunshine or by means of a lens.

When analyzed in this way all natural colors are found to be compound.

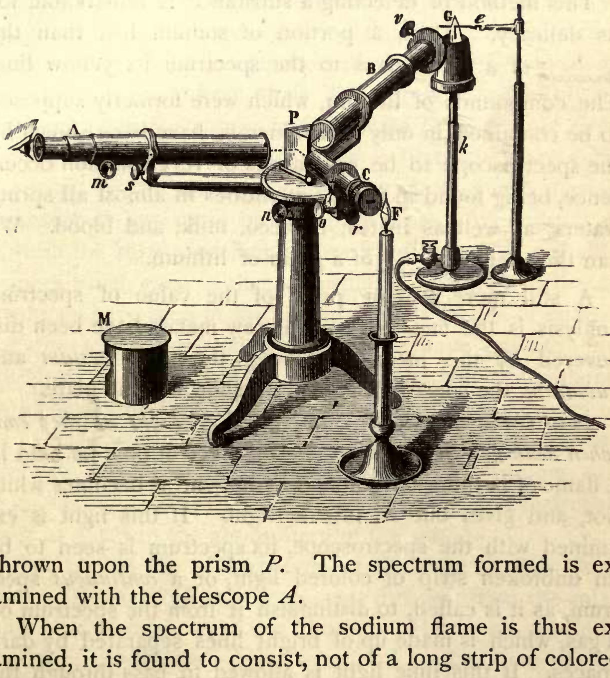
109. *Spectrum Analysis.* — Let us now analyze more thoroughly the light given out by luminous bodies. We will begin with colored flames.

If a piece of platinum wire be dipped in a solution of soda, and held in the colorless flame of an alcohol lamp, or a Bunsen's gas-burner, the flame becomes of an intense yellow. This color is due to the heated vapor of sodium in the flame. If we dip another platinum wire in a solution of lithium, and hold it in the colorless flame, a rich crimson hue is imparted to the flame. The vapor of copper colors the flame green. Other metals give characteristic colors to the flame.

110. *The Spectroscope.* — These colored flames can be

best analyzed by means of the *spectroscope*, shown in Figure 83. The light from the flame is admitted through a narrow slit into the tube *B*, where it is concentrated by lenses and

Fig. 83.



thrown upon the prism *P*. The spectrum formed is examined with the telescope *A*.

When the spectrum of the sodium flame is thus examined, it is found to consist, not of a long strip of colored light, like the solar spectrum, but of a single bright yellow line, as shown at III. in Plate I. When other flames colored by metallic vapors are examined, it is found that their spectra in all cases consist of bright lines separated by dark spaces. In Plate I., II. shows the spectrum of *potassium;* IV. the spectrum of *cæsium;* and V. that of *rubidium.*

The spectrum of each substance always consists of the same lines in the same relative positions. Hence the spectroscope furnishes a ready means of detecting the presence of any substance; for, even when several substances are mixed, each gives to the spectrum the characteristic lines which cannot be mistaken.

This method of detecting a substance is remarkable for its delicacy. Thus, a portion of sodium less than the $\frac{1}{180,000,000}$ of a grain gives to the spectrum its yellow line. The compounds of lithium, which were formerly supposed to be contained in only four minerals, have been shown by the spectroscope to be substances of very common occurrence, being found in minute quantities in almost all spring waters, as well as in tea, tobacco, milk, and blood. We can thus detect $\frac{1}{6,000,000}$ of a grain of lithium.

A still more striking proof of the value of spectrum analysis is the fact that several new metals have been discovered by this means. Among these are *cæsium* and *rubidium*, the spectra of which are shown in the plate.

111. *Gases absorb the Same Kind of Light as they emit when heated to Incandescence.* — If a piece of lime be held in a flame of burning oxygen and hydrogen,* it becomes white hot, and gives out an intense light. If this light is examined with the spectroscope, its spectrum is seen to be an unbroken strip of colored light, or a *continuous* spectrum, as it is called, to distinguish it from the spectrum of a gas, which is made up of bright lines separated by dark spaces. If this lime light is allowed to pass through the yellow sodium flame, and is then examined with the spectroscope, a dark line is seen to occupy the place of the yellow line of the sodium spectrum. This must be due to the fact that the sodium vapor has absorbed just the kind of light which it gives out, and thus caused that portion of the spectrum to be comparatively dark. In this case the sodium spectrum is said to be *reversed.* In like manner

* See the "Chemistry" of the "Cambridge Physics," §§ 132, 185.

the spectra of many other substances have been reversed, each substance in a state of vapor having the power to absorb the same rays which it gives out when heated to incandescence.

112. *Fraunhofer's Lines.* — When the light of the sun is examined with a spectroscope, it is found that the spectrum is crossed by a great number of dark lines, known as *Fraunhofer's lines*, from their discoverer. A few of the stronger ones are shown at I. in Plate I. The only satisfactory explanation of these lines is that the white light given out by the solid or liquid mass of the sun is partially absorbed by vapors in his atmosphere. We must then have in the solar spectrum the reversed spectra of the substances which exist in that atmosphere. Strange as it may seem, we have then in the spectroscope a means of analyzing the atmosphere of the sun. We have only to find whether the dark lines in the solar spectrum correspond with the bright lines in the spectra of substances known to us. Many such coincidences have been detected, and we are now quite certain that iron, sodium, magnesium, calcium, chromium, nickel, barium, copper, zinc, and hydrogen exist as gases in the atmosphere of the sun.

Nor is this all. The spectra of the stars all show dark lines. These are for the most part different from the solar lines, and from those of one another. Hence we conclude that the composition of the solar and stellar atmospheres is not the same. Many of the substances known on this earth have been detected in the atmosphere of the stars by Huggins and Miller, to whom we owe this important discovery. The star known as Aldebaran has in its atmosphere hydrogen, sodium, magnesium, calcium, iron, tellurium, antimony, bismuth, and mercury; while in the atmosphere of Sirius only sodium, magnesium, and hydrogen have with certainty been detected.

SUMMARY.

Different bodies absorb light of different colors. It is the sifting of the rays of light by absorption which gives bodies their color. (106, 107.)

The color of bodies may be analyzed by means of a prism. (108.)

Different substances emit light of different colors. (109.)

Incandescent gases give dark spectra crossed by bright lines.

The presence of any substance in the flame can be detected by means of the spectroscope. (110.)

By means of the lime or magnesium light, the spectra of the elements may be *reversed*, since a substance absorbs readily those rays which it can emit. (111.)

Solar and stellar spectra are crossed by dark lines, known as *Fraunhofer's lines*. These are due to absorption.

The composition of the atmosphere of the sun and stars may be ascertained by analyzing their light. (112.)

INTERFERENCE AND THE UNDULATORY THEORY OF LIGHT.

113. *Colors of Soap-Bubbles.** — If a soap-bubble be blown in a clear circular saucer, so as to be somewhat more than hemispherical, and then be placed under a glass cover to keep it from gusts of air, the colors which in the blowing had wandered irregularly over its surface will gather into regular concentric rings at its top. If the bubble be a thick one, only faint colors will appear at first; but they will gradually grow more vivid. Each color, however, does not become brighter, but spreads away, and a new and richer one takes its place. In this way the

* See Appendix, IV.

rings go on increasing in number and brilliancy, until at length a very clear white spot appears at the top, and is quickly followed by a perfectly black one. Soon after this the bubble bursts. During all this time the bubble has been gradually becoming thinner by the slow running down of the liquid from the top. The ring-like arrangement of the colors around the thinnest part of the bubble as a centre seems to show that the tint depends upon the thickness of the liquid film at the point where the color appears; a certain tint being developed at a certain thickness and at no other. The order of the colored rings and of the tints in them is always the same, after the black central spot has once formed. None of these tints are pure prismatic colors. To see them to the best advantage the bubble must be illumined by diffused light, not by direct sunlight.

If the bubble is illumined by letting the colors of the spectrum fall upon it one by one, when the red light falls upon it the rings will appear all red, separated by black spaces; when the yellow light falls upon it, they will be yellow with black spaces; and so on for all the colors. In all cases the rings are more numerous than when the bubble is illumined by white light, but the diameter and breadth of the rings vary with the color used, being greatest for the red and least for the violet.

This explains the composite colors of the rings when white light is used; for in this case we have the rings of the seven colors overlapping one another in various ways so as to produce a variety of tints.

114. *These Colors do not depend upon the Liquid of which the Bubble is made.* — What now is the cause of these colored rings? They do not depend on the material of which the bubble is made, for a film of any substance whatever will produce them, if it be thin enough. They are seen in the oily scum upon stagnant water; in the

gayly painted wings of insects; and even on polished steel. Bubbles may be blown with a variety of liquids and even of glass, and they all display the same hues in the same order. In fact it requires no medium at all to produce them, but only an interval between two reflecting surfaces. They are seen in a crack which does not extend completely through a thick piece of glass, and in mica when two of its layers are partially separated. It may be said that there is air between the surfaces; but under the exhausted receiver of an air-pump the rings remain unchanged.

115. *These Colors are due to Interference.* — It is, then, to the interval between the reflecting surfaces that we are to look for the origin of these colors. A part of the light will of course be reflected at each surface, and the rays reflected from both will take very nearly the same direction. When simple or *homogeneous* light, as it is called, is allowed to fall on the bubble, the colored rings, as we have seen, are separated by dark spaces. At certain distances between the surfaces, then, the rays of light reflected from them destroy each other, and produce darkness; while at other distances they combine and produce more intense light. Since the rings of the more refrangible colors are narrower, it follows that the distances at which the rays of these colors destroy each other are less than for the less refrangible rays. The rays which destroy each other are said to *interfere*, and the colored rings are evidently due to interference.

116. *The Undulatory Theory of Light.* — We have now seen that rays of light are reflected, are refracted, and interfere in the same way as those of sound. It seems probable, then, that both light and sound are propagated in the same way. We have seen that sound is propagated by means of *waves*, and it is therefore probable that light is propagated by waves. We have seen, too, that sounds interfere with each other so as to produce silence, when their

waves meet in opposite phases (36); and from the way in which sounds interfere we should be driven to conclude that sound is propagated by waves, even if we did not know the fact already. Do the rays of light interfere in such a way as to show that light is propagated by waves?

117. *When Light is reflected from the Surface of a Rarer Medium, the Phase of the Wave is Changed.* — We have seen in the soap-bubble that as the top becomes very thin it appears black, and the blackness grows more intense until the thickness becomes nothing, and the bubble bursts. Just before it bursts, the two surfaces of the film are virtually together, and the rays reflected from them must therefore start back together; and it would seem that they should produce light instead of darkness, — that is, that their phases should coincide rather than interfere, — if light, like sound, is really propagated by waves.

This interference, then, seems at first inconsistent with the wave theory of light. The following illustration of Herschel's, however, will show how it is reconciled with that theory. Imagine a number of ivory balls all of a size placed in a row, in contact with one another, but connected only by a rubber cord which runs through them all and is fastened at the centre of each. Let an ivory ball of exactly the same size be driven against the end of the row. According to the law of the collision of elastic bodies, this ball will give up all its motion to the one it strikes, and this to the next, and so on to the end of the row. None of the balls move except the last, but they are all made to press against one another, and a *wave of compression* may be said to run along the line. The last ball has nothing to which to give its motion, and therefore starts off; but it is quickly checked and drawn back by the elasticity of the rubber cord. But at the same time it pulls the next ball forward, and this the next, and so on to the end of the line. In this way a *wave of extension* runs back along the row.

Here then the direct wave changes its phase on being reflected. This is, however, an extreme case, and unlike anything which we find in the transmission of light; for when it passes from one medium into another there are always particles beyond to which the moving particles can impart their motion. Let us now suppose that there is a second row of smaller elastic balls, near the end of the first, and arranged exactly in the same way; and that at the end of the first there is a detached ball of the same size as those in the second row. The line of larger balls will represent the condition of the particles of a denser medium in contact with those of a rarer one. Let now an impulse be sent along the row of larger balls, as at first. The last ball of the line drives the detached ball off against the first ball of the second row, and thus sends forward a wave of compression. But the smaller ball will not carry off all the motion of the larger one, which will also advance till it is checked by the rubber cord. While this ball is drawn back it draws forward the ball behind it, and this the next, and so on. In this case, part of the wave is reflected, and in an opposite phase from the direct wave.

If the balls in the first row are smaller than the detached ball and those in the second row, they will represent the condition of the particles of a rarer medium in contact with those of a denser one. If an impulse be sent along the first line, as before, the detached ball will not only move forward, but also cause the ball behind it to rebound. Here the reflected wave has the same phase as the direct one.

When, therefore, a wave is reflected from a rarer medium, it changes its phase; but not when reflected from a denser medium.

We see, then, that the fact that the top of the bubble is black is not an objection to the theory that light is propagated by waves; for at the outer surface of the bubble the rays of light are reflected from a denser medium, while at the inner surface they are reflected from a rarer medium, and they should therefore start back in opposite phases when the surfaces are together.

118. *When Homogeneous Light is used, the Distance between the Reflecting Surfaces at the second, third, and fourth Dark Rings is twice, thrice, and four times that at the first, and so on.* — If the dark rings are due to the meeting of waves of opposite phases, the distance between the reflecting surfaces at the second ring should, when homogeneous light is used, be twice as great as at the first; at the third, thrice as great as at the first; and so on. For at the first ring the light reflected from the inner surface must travel over a distance of a wave-length more than that reflected from the outer surface, in order that the waves may meet in the opposite phase; and at the second ring it must travel over the length of two waves more; at the third ring, over the length of three waves more; and so on. Is this the case?

The thickness of the soap-bubble at the different points cannot be directly measured; but we have seen that the rings can be obtained by other means. The following arrangement enables us readily to measure the distance between the reflecting surfaces.

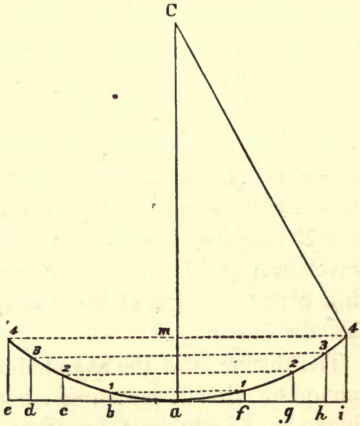
Upon a perfectly flat and smooth plate of glass is placed another piece equally smooth, but with its under surface slightly curved, as shown in Figure 84. This curved surface should be a portion of the surface of a sphere whose radius is some 40 or 50 feet. When this curved glass is pressed firmly down upon the plate, the centre appears black, and is surrounded by colored rings (Figure 85), as in the soap-bubble. Suppose that homogeneous light of some color,

Fig. 84.

as red, be allowed to fall perpendicularly upon the upper glass. Dark rings will be formed at 1, 2, 3, and 4 (Figure 86), and the diameters 1 1, 2 2, etc. of these rings can be easily measured. They are always found to be in the proportion of 1, 1.414, 1.732, 2.000, and so on. Now these numbers are the square roots of the numbers 1, 2, 3, 4, and so on; and we know from the form of the sphere that the distances 1 *b*, 2 *c*, 3 *d*, 4 *e*, etc. are to one another as the squares of the chords 1 1, 2 2, 3 3, 4 4, etc. Hence the distance between the reflecting surfaces at the second dark ring is twice that at the first, and so on.

Fig. 85.

Fig. 86.



119. *Light is propagated by means of the Ether.* — We have now seen that light interferes in such a way as to show that it is propagated by waves. If, however, a lighted lamp be placed behind the receiver of an air-pump, and the air be exhausted, the flame still shines through the receiver, showing that light is not propagated by means of the air, as is the case with sound. We know also that the heavenly bodies are far beyond the limits of the earth's atmosphere, which extends to a height of only about 50 miles.

We must therefore conclude that all space is filled with an elastic medium through which the light-waves are propagated as the sound-waves are sent through the air.

This medium is called the *ether*, and it fills not only the spaces between the heavenly bodies, but also those between the molecules of all substances. It cannot be exhausted from a receiver, since it readily passes through the glass.

120. *The Length of the Light-Wave.* — We have seen that the light reflected from *f* (Figure 86) must travel a wave-length farther than that reflected from 1, in order that the waves reflected from these points may meet in opposite phases, and so give a dark ring. Now the wave reflected from *f* must evidently travel over the space 1 *f* twice: hence 1 *f* must be ½ the length of a luminous wave, and we have seen that this is ¼ of 4 *i*. Now we can easily find the length of 4 *i*. 4 *m* is half the diameter of the fourth bright ring, and can be found by measurement. We know the length of the radius 4 *C*, and 4 *m C* is a right-angled triangle. In this triangle we know the length of the hypothenuse 4 *C*, and of the side 4 *m*. Hence we can find the length of *C m*. The radius $Ca - Cm = am = 4\,i$.

In this way the lengths of the waves of light of the different colors have been found. The following table shows the lengths of these waves, and also the number that enter the eye in a second: —

Colors	Length of waves in parts of an inch.	Number of waves in an inch.	Number of waves in a second.
Extreme Red	.0000266	37,640	458,000,000,000,000
Red	.0000256	39,180	477,000,000,000.000
Orange	.0000240	41,610	506,000,000,000,000
Yellow	.0000227	44,000	535,000,000,000,000
Green	.0000211	47,460	577,000,000,000,000
Blue	.0000196	51,110	622,000,000,000,000
Indigo	.0000185	54,070	658,000,000,000,000
Violet	.0000174	57,490	699,000,000,000,000
Extreme Violet	.0000167	59,750	727,000,000,000,000

According to Eisenlohr the length of the waves in the extreme red ray is just double the length of the waves in the invisible rays beyond the violet. The whole range of rays, then, extends only over what is equivalent to a single octave in music.

121. *The Origin of Light.* — We have now seen that light, as well as sound, is propagated by waves in an elastic medium, and that sound originates in vibrations of the particles of the sounding body. It is very probable, then, that light also has its origin in the vibrations of the particles of a luminous body. In ordinary combustion, which is the most familiar source of light, the atoms of the oxygen in the air are rushing into combination with the atoms of the burning body; and the collision of these atoms will be very likely to set them vibrating. These vibrations will be communicated to the atoms of the surrounding ether, and by these transmitted to the eye. The color of the light depends on the rapidity of the vibrations.

The particles of certain substances seem to be capable of vibrating in all periods, and thus of producing white light; while those of other substances seem to be capable of vibrating only in particular periods, and therefore they produce light of different colors. It is seldom, however, that the vibrations of the molecules are limited to one period, and therefore that a luminous body gives out homogenous light. We can now understand how it is that we can detect certain substances by the light they give. Their particles can vibrate only in certain ways, and they of course cause the particles of ether nearest them to vibrate in the same way. The vibrations are sent on unchanged from particle to particle of the ether, and are ready at any point to reveal the nature of the substance in which they originated. The vibrations are so minute that it would seem impossible to find out their character, but the spectroscope enables us to do this with ease and accuracy.

When a number of strings of different lengths and tension are stretched in the air, as in the Æolian harp, they absorb all the vibrations accordant to their own which fall upon them, while they allow all the discordant ones to pass on. In much the same way we must imagine the molecules of a body suspended in the ether, from which they absorb all accordant vibrations while they transmit all discordant ones.

Transparency is then synonymous with discordance, and opacity with accordance. This explains the fact that different substances absorb light of different colors, and also the fact that incandescent gases give out light of the same color as that which they absorb.

122. *Diffraction Fringes.* — Take a glass lens whose focal length is about an inch, and let a beam of sunlight fall upon it in a darkened room. The light will be concentrated into a very small image of the sun about an inch from the lens, and will then diverge from it in a luminous cone, and may be received upon a screen. Place any small opaque body within this cone of light, so that it may cast a shadow upon the screen. This shadow, instead of being sharply defined, as we should expect (85), is somewhat larger than it should be, and is surrounded by three colored fringes, the outer one being extremely faint. If homogeneous light is used, instead of the fringes we get bright rings separated by dark spaces, the breadth of the rings varying with the color of the light. When white light is used, these different sets of colored rings blend so as to produce the fringes.

If the opaque body is long and very narrow, as a hair or a very thin strip of card, besides the colored fringes already described, others are seen within the shadow, parallel to its length, and similarly arranged on the two sides of a central white line.

When light is transmitted through a very narrow slit, the fringes become even more curious and complicated.

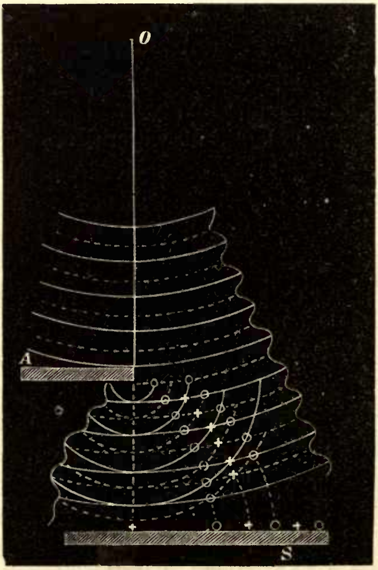
To see these diffraction fringes to the best advantage, a magnifying glass should be used, putting the eye in place of the screen.*

123. *Diffraction Fringes are produced by Interference.* — Diffraction fringes are fully explained by the interference of light, according to the undulatory theory. Suppose *a b* (Figure 87) to be a portion of a wave of light. Every particle of ether along this curve is a centre of a set of waves, which tend to run not only forward but sideways as well.

Fig. 87.

But as each particle sends equal waves in opposite directions at the same instant, the lateral waves destroy one another; while the advancing portions unite to form one continuous wave. When, however, the wave meets an opaque body (Figure 88), the particle of ether nearest the edge of the opaque body, since there are vibrating particles on only one side of it, can start a new set of waves. These waves meet the original waves in opposite phases at the points marked by the little circles; in the same phases at the points marked by the crosses. They of course interfere in the former

Fig. 88.



* See Appendix, V.

case and coincide in the latter, and thus give rise to the colored fringes.

If the opaque body is narrow, as shown in Figure 89, the waves which start up at each edge of it interfere and coincide behind it, so as to produce the interior fringes and the central bright line. That these interior fringes are due to the interference of the waves which thus bend round the edges of the opaque body is clearly shown by their disappearance when the light is cut off from one edge by a screen.

Fig. 89.

SUMMARY.

Soap-bubbles and other thin films, when exposed to light, exhibit colored rings. (113.)

These rings are always seen when light is reflected from two surfaces separated by a very small interval. (114.)

They are caused by interference. (115.)

Light, like sound, is propagated by means of waves. (116.)

When light is reflected from the surface of a rarer medium, the phase of its wave is changed. (117.)

Light is propagated by means of the ether. (119.)

The length of the luminous waves can be found by means of interference rings. (120.)

Light has its origin in the vibrations of the molecules of a luminous body.

The molecules of a body are usually capable of vibrating in several periods. Hence a luminous body seldom gives out homogeneous light.

A body absorbs such vibrations as are accordant with those of its own molecules, and reflects or transmits such as are discordant. (121.)

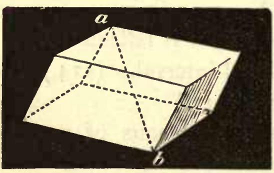
When small bodies are seen in divergent light, they appear surrounded by colored fringes, called *diffraction* fringes. (122.)

These fringes are caused by interference. (123.)

DOUBLE REFRACTION AND POLARIZATION.

124. *Uniaxial and Biaxial Crystals.* — We have now seen that a beam of ordinary light is an assemblage of minute vibrations of different periods, and we have studied somewhat the effect of a transparent uncrystalline body on such a beam. We will next study the effect of transparent crystals on the same. We will select for this purpose a crystal of *Iceland spar* (crystallized carbonate of lime). Such a crystal is shown in Figure 90. A crystal of this shape is called a *rhomb*. It has six faces, which are equal parallelograms. These parallelograms are so arranged that three of them have one of their obtuse angles at *a*; and the other three, one of their obtuse angles at *b*. The parts of the crystal are therefore arranged symmetrically about the line *a b*, which is called the *axis* of the crystal.

Fig. 90.



If now a ray of light be allowed to fall on one face of this crystal in a darkened room, it will be divided into two rays. One of these rays is found to conform to the law of ordinary refraction, and is therefore called the *ordinary* ray. The other ray does not lie in the same plane as the incident and the ordinary rays, and does not conform to the law of sines (93). It is therefore called the *extraordinary* ray. By cutting parallel plates from a rhomb of Iceland spar in various directions, it is found that, when the plates are cut perpendicularly to the axis of the crystal, they will allow a ray of ordinary light to pass through them perpendicularly without dividing it into two parts; but this is true of plates cut in no other direction. In other words, a ray of light which passes through a rhomb of Iceland spar parallel to its axis is not *doubly refracted;* while every ray which passes through it in a different direction is thus refracted. For this reason the axis of the crystal is also called its *optical* axis. The ordinary and extraordinary rays separate most widely when they pass through the crystal perpendicularly to its optical axis.

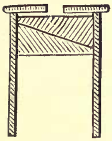
In many crystals, as saltpetre and mica, there are two directions in which light may pass through them without being doubly refracted. Such crystals have two optical axes and are called *biaxial* crystals, to distinguish them from *uniaxial* crystals, which have only one such axis.

When a ray of light passes through a biaxial crystal in such a direction as to be doubly refracted, both rays are usually extraordinary rays.

125. *The Double-refracting Prism.* — Since the opposite faces of a rhomb of Iceland spar are parallel, the ordinary and extraordinary rays emerge from the crystal parallel to the incident ray and to each other, but quite near together. If, however, the crystal be cut into the form of a prism in such a way that its refracting edge may be parallel to the optical axis, the ordinary and extraordinary rays, after leav-

ing the prism, will diverge, so that we may easily insulate either and examine it separately. Such a prism will of course disperse both rays so as to produce spectra, but it may be rendered sufficiently achromatic by combining with it a second prism of glass, whose dispersive power is different from that of the crystal. This prism is usually mounted as shown in Figure 91.

Fig. 91.



126. *The Ordinary and Extraordinary Rays are both Polarized.* — If a beam of ordinary light be allowed to fall on a double-refracting prism, and the extraordinary ray be cut off by a screen, and the ordinary ray be allowed to fall on a second similar prism whose refracting edge is held parallel to that of the first, it will be refracted *singly* and *ordinarily.* If the refracting edge of the second prism be held perpendicular to that of the first, the ray wiil be refracted *singly* but *extraordinarily.* In every intermediate position, it will be *doubly* refracted, more of the light passing into the ordinary or the extraordinary ray according to the inclination of the edges of the two prisms. At an inclination of 45°, the light is equally divided between the two; in passing from 45° to 90°, more and more of the light passes into the extraordinary ray; from 45° to 0°, more and more into the ordinary ray.

If the ordinary ray be cut off, and the extraordinary ray be allowed to fall on the second prism, it will be refracted *singly* and *extraordinarily* when the edges of the prisms are parallel; *singly* and *ordinarily* when the edges are perpendicular; *doubly* in every other position.

If the ordinary ray be allowed to fall upon a flat plate of tourmaline whose faces are cut parallel to the optical axis, it will be found, when the plate is held in a certain position, that the ray is wholly absorbed; but when the plate is turned round from this position, a part of the ray begins to be transmitted; and when it has been turned through 90°, the whole ray is transmitted.

If the extraordinary ray be allowed to fall on the tourmaline, it will be wholly transmitted where the ordinary ray was wholly absorbed, and absorbed where that was transmitted.

If the ordinary ray be allowed to fall on a smooth plate of glass at an angle of incidence of 56½°, it is found that, when the plate is held in a certain position with reference to the ray, it will be wholly reflected. On turning the glass round, keeping the angle of incidence unchanged, the ray begins to be partly transmitted, and when the glass has been turned through 90° it is wholly transmitted. If the extraordinary ray be used, it will be transmitted where the ordinary ray is reflected, and reflected where that is transmitted.

The above experiments show that both the ordinary and extraordinary rays are different on different sides. When the prism of Iceland spar was turned round through 90°, the ray which had been at first refracted *ordinarily* was refracted *extraordinarily*. When the tourmaline was turned round through 90°, the ray which had been *absorbed* was *transmitted*. When the glass plate was turned round through 90°, the ray which had been *reflected* was *transmitted*.

Both rays, then, have acquired *sides*, so to speak; and the corresponding sides of the two rays are *at right angles* to each other. In other words, the extraordinary ray is like the ordinary ray turned round through 90°.

Light which has thus acquired sides is said to be *polarized*. The ordinary ray is said to be polarized in a plane parallel to the optical axis of the crystal; and the extraordinary ray in a plane at right angles to that axis.

127. *The Explanation of Polarization and Double Refraction.* — We have now seen that both light and sound are

propagated by vibrations, and that a ray of light when polarized has acquired sides. In a sound-wave, the particles are vibrating to and fro in the direction in which the wave is advancing, and it is therefore difficult to imagine how a ray of sound can have sides. We are therefore driven to conclude that the ethereal particles vibrate in a direction *transverse*, or at right angles, to the direction in which the wave is moving. How such vibrations would make the wave different on different sides will be readily seen from the following illustration.

If *a b* (Figure 92) be a rope fastened at *a* and held by the hand at *b*, and the hand be moved up and down, waves will run along the cord in the direction of its length. The particles of the cord will vibrate up and down, or transversely to this direction of the waves. The cord thus vibrating represents a ray of light in which the vibrations are transverse, and it will be seen at a glance that such a ray will be different at the right and the left from what it is above and below, or, in other words, that, like polarized light, it has sides.

Fig. 92.

If the hand be moved to and fro horizontally, the sides will be above and below rather than at the right and the left, as at first. If the cord in the first case be taken to represent an ordinary ray, it will in the second case represent an extraordinary ray.

If the hand be moved rapidly to and fro, first up and down, then obliquely, then right and left, and so on around, the particles of the cord will be made to vibrate in these different directions in rapid succession. If the particles of the ether are vibrating in the same way, it is evident that the ray can have no sides, since it would be alike above and below, to the right and to the left. It is possible, then, even with transverse vibrations, to have a ray of light without sides, as is the case with ordinary light.

We conclude, then, that light is propagated by *transverse* vibrations; and that in a ray of ordinary light these vibrations take place in every plane. On passing through certain crystals, as Iceland spar, these vibrations are sifted and arranged in two sets; the vibrations in one set being in one plane, and those in the other set being in a plane at right angles to this.

One of these sets is retarded more than the other in passing through the crystal, and is therefore bent more from its course; and this is generally the ordinary ray.

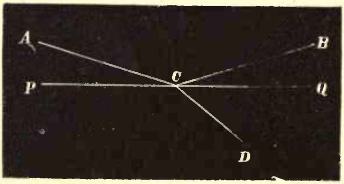
The extraordinary ray also passes through the crystal more readily in some directions than in others, and hence it is usually refracted, even when the incident ray falls perpendicularly upon the crystal; and it seldom lies in the same plane with the incident and ordinarily refracted rays.

128. *Action of Tourmaline on Ordinary Light.* — If a ray of ordinary light be allowed to fall upon a flat plate of tourmaline, like that described above, and the transmitted light be allowed to fall on a second similar plate, it will be wholly transmitted when the plates are parallel, and wholly absorbed when they are at right angles; while in intermediate positions it will be partly transmitted and partly absorbed. If the light which has been transmitted through the first plate be received upon a plate of glass at an angle of incidence of $56\frac{1}{2}°$, it will be wholly reflected, in a certain position of the glass, and wholly transmitted when the glass has been turned round through 90°. The ray is reflected and transmitted in the same manner as the extraordinary ray obtained by refraction in a crystal of Iceland spar.

The tourmaline, then, not only impedes one set of vibrations more than the other, but wholly absorbs those which are parallel to its optical axis, while it allows those at right angles to this axis to pass readily.

129. *Light Polarized by Reflection and Refraction.*—If a ray of ordinary light *A C* (Figure 93) fall upon a plate of glass *P Q* at an angle of incidence of 56½°, a small part *C B* will be reflected, and the remainder *C D* transmitted. On examination the reflected portion will be found to be wholly polarized in the plane of reflection; and the refracted portion will be partially polarized in a plane at right angles to this; the refracted beam containing just as much polarized light as the reflected one. At any other angle of incidence the reflected portion is only partially polarized. When the reflected ray is wholly polarized, as above, its direction is always perpendicular to the refracted ray.

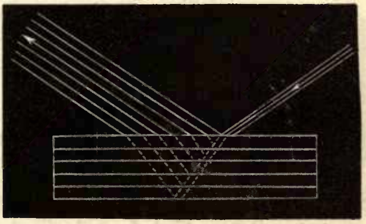
Fig. 93.



Light is wholly polarized by reflection from other substances, as water, diamond, and the like; but the angle at which complete polarization takes place, or the *polarizing angle*, as it is called, is different in different substances. For water, the polarizing angle is 53° 11′; for diamond, 68° 6′; but in every case the reflected ray is perpendicular to the refracted one.

When light falls upon glass at the polarizing angle, the reflected portion is, as we have seen, wholly polarized; but the reflected portion is only about $\frac{1}{30}$ that of the transmitted, and consequently has but feeble intensity. If, however, several plates of glass are laid one upon another, as in Figure 94, more and more of the light will be polarized on reflection from each surface. In this way, if plates enough are used, the ray will be divided into two nearly equal portions, each wholly polarized in planes at right angles to each other. A frame containing five or six squares of good window glass, laid one upon another and backed with a piece of black velvet, is one of the cheapest and best instruments for getting polarized light.

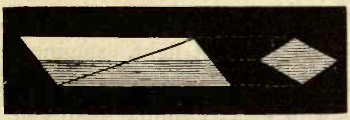
Fig. 94.



130. *Polarizer and Analyzer.* — Any instrument used to polarize light is called a *polarizer;* and any instrument used to examine polarized light is called an *analyzer.* Thus a tourmaline plate, when used to polarize light, is a polarizer; but when used to examine polarized light, it is an analyzer.

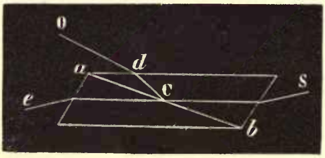
131. *Nicol's Prism.* — Nicol's prism is one of the most valuable means of polarizing light, for it is perfectly colorless, polarizes light completely, and, like tourmaline, allows only one beam to pass. It is made from a rhomb of Iceland spar, about an inch in height, and a third of an inch in breadth. The rhomb is first bisected in the plane which passes through the obtuse angles, as shown in Figure 95. The two halves are then joined together again with Canada balsam.

Fig. 95.



The principle of Nicol's prism is this: the refractive index of Canada balsam (1.549) is less than the ordinary index of Iceland spar (1.654), but greater than its extraordinary index (1.483). Hence, when a luminous ray *S C* (Figure 96) enters the prism, the ordinary ray undergoes total reflection at the surface of the Canada balsam *a b*, and takes the direction *C d O*, and thus is carried out of the prism; while the extraordinary ray *Ce* emerges alone. This prism can, like tourmaline, be used either as a polarizer or an analyzer. It is better than tourmaline, since the latter is always colored.

Fig. 96.



132. *Interference of Polarized Light.* — Two rays are said to be *similarly* polarized when they are polarized in the same plane, and *oppositely* polarized when polarized in planes at right angles to each other. If now in polarized light the particles all vibrate in the plane of polarization, it will at once be seen that only similarly polarized rays can interfere so as to destroy each other; for it will be remembered that, where waves interfere, the particles are compelled to remain at rest by being urged by equal forces to move in opposite directions. This of course cannot take place when particles are moving to and fro in planes at right angles to each other, but only when they are moving to and fro in the same plane.

Cut two parallel slits very near each other in an opaque screen, place it before a brilliant point of light, examine it with a magnifying glass, and interference fringes will be seen. Cover now both slits with exactly similar plates of tourmaline. When the plates are parallel, the rays which they transmit are *similarly* polarized; when they are at right angles to each other, the transmitted rays are *oppositely* polarized. In the first case the fringes are distinctly seen, but they wholly disappear in the second.

We thus see that experiment and theory agree with respect to the interference of polarized light.

133. *Circular and Elliptical Polarization.* — Although vibrations cannot destroy each other unless they are performed in the same plane, it does not follow that they

cannot disturb each other at all. When a boat is rowed against a stream with a force just equal to that of the current, it remains at rest. When, however, it is rowed across the stream, it does not remain at rest, although it does not take the same course it would were there no current. In this case the boat would move in a straight line, and in a direction diagonal to that of the current and that in which the boat is rowed. Again, when a ball is thrown horizontally, it does not move in a straight line, as it would were no other force acting upon it, but is compelled by gravity to move in a curved path. So, too, when two rays of light whose vibrations are performed in different planes meet, the resulting vibrations are sometimes in a direction diagonal to those of the components; and sometimes, instead of moving to and fro in straight lines, the particles are made to describe curved paths. When they are made to move in circles, the light is said to be *circularly* polarized, and when they move in ellipses, it is said to be *elliptically* polarized.

When a ray of polarized light is reflected from a polished surface in a different plane from that in which it is polarized, it becomes elliptically polarized; when it is reflected from a metallic surface, this ellipticity becomes very considerable. When such a ray is totally reflected, it may become circularly polarized.

134. *Rotatory Polarization.* — When a ray of polarized light is transmitted along the optical axis of quartz and a few other crystals, and through certain liquids, its plane of polarization is twisted round more or less, according to the thickness of the medium traversed. This is called *rotatory* polarization. Some substances turn the ray round to the right, and some to the left, but the same substance always turns it in the same direction. The amount of twisting of the ray is different for each of the prismatic colors.

Light polarized in this way appears to the unaided eye like ordinary light. When, however, it is analyzed by Nicol's prism or a tourmaline plate, the light appears colored, the tint varying with the thickness of the medium traversed by the ray. For the same thickness of the medium, the tints change as the analyzer is turned round the ray. When the plane of polarization has been rotated to the right, we get a certain succession of tints on turning the analyzer to the right. When the plane has been rotated to the left, we get the same succession of tints on turning the analyzer to the left. These tints therefore enable us to detect this kind of polarized light, and to determine whether the plane has been rotated to the right or to the left.

A solution of sugar rotates the plane of polarization to the left, and the amount of sugar in a solution can be ascertained by passing a ray of polarized light through it, and noticing the tints which it gives upon analysis. An instrument used for this purpose is called a *saccharometer* (sugar-measurer.)

The production of the tints when this kind of polarized light is analyzed is easily explained. Suppose a tourmaline plate is used as the analyzer. It will be remembered that the amount of polarized light absorbed by such a plate varies with the plane of polarization. Now, as the plane of each prismatic color is rotated a different amount, it follows that the colors will be absorbed in different proportions by the tourmaline, and the transmitted ray of light cannot therefore be white, but must be of the color complementary to that absorbed. As the plate is turned round, the tints will change, since the proportion in which the different colors are absorbed will change.

When a Nicol's prism is used as an analyzer, the different tints are due to the fact that only one of the rays is transmitted, and that the amount of light which passes into the ordinary and extraordinary ray differs with the angle of polarization and the position of the prism with reference to the ray.

135. *Colors exhibited by Crystalline Plates on Exposure to Polarized Light.* — If a crystalline plate cut from a uniaxial crystal perpendicular to the optical axis be held between the eye and a source of polarized light, nothing is seen which would lead to the suspicion that the plate is anything more than an ordinary piece of glass. If, however, the light which has passed through the plate be analyzed before it enters the eye, a series of brilliantly colored rings will appear. These rings change their color and their brilliancy as the analyzer is turned round. When the analyzer is in one position, the rings are crossed by two white bars at right angles to each other (Figure 97); and when the analyzer has been turned through 90°, these white bars are replaced by black ones (Figure 98),

Fig. 97.

Fig. 98.

while the colors of the rings are changed to their complementary ones.

When the plates are properly cut from biaxial crystals, two sets of rings and bars are seen, as shown in Figures 99, 100, and 101.

These rings are due to the interference of polarized rays. Their mode of formation, and the reason that they appear only when the analyzer is used, will be evident on referring to Figures 102 and 103. Every ray of

Fig. 99.

Fig. 100.

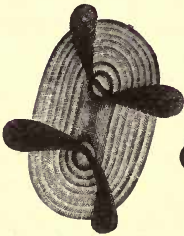
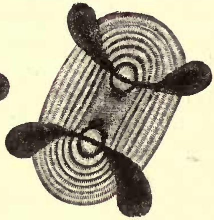
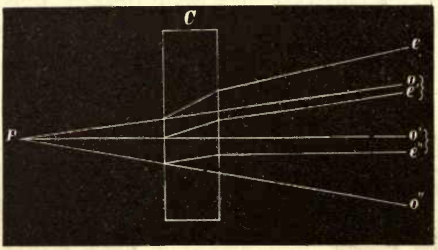


Fig. 101.



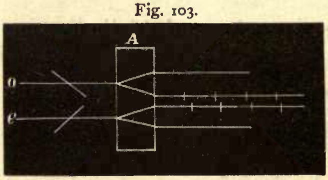
polarized light diverging from *P* is separated, on passing through the crystalline plate *C*, into an ordinary and an

Fig. 102.



extraordinary ray. The only rays which would come together so that they could interfere, as seen in Figure 102, are the ordinary ray of one set and the extraordinary ray of the next, as o e' and o' e''. These rays are unequally retarded in passing through the plate, and would therefore be in a

Fig. 103.



condition to interfere were they not oppositely polarized. When, however, these rays fall on the analyzer *A*, each is again divided into an ordinary and an extraordinary ray. Of these rays two are suppressed, while two, polarized in the same plane, are allowed to pass on, and in doing so interfere and produce the colored rings.

136. *Other Phenomena of Polarization.* — Transparent substances, like glass, when their particles are subjected to unequal strain, have the same effect upon polarized light as crystalline plates. If a ray of polarized light be allowed to pass through a plate of well-annealed glass, and then be examined with the analyzer, no colored rings appear. Rings, however, appear as soon as any strain is brought to bear upon the glass either by pressure or by the unequal heating of its parts. When unannealed glass is used, the rings are very brilliant, and have different forms accord-

Fig. 104.

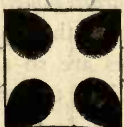


Fig. 105.

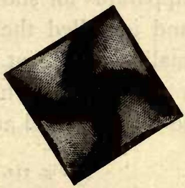


Fig. 106.

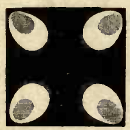


Fig. 107.

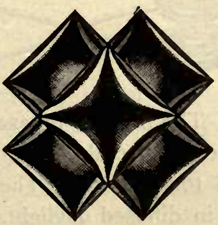


Fig. 108.

Fig. 109.

ing to the way in which the glass is cut, as shown in Figures 104 – 109.

Again, place a piece of borax glass within a helix of copper wire, and allow a ray of polarized light to pass through it. The ray is unchanged; but as soon as the electric current is sent through the helix, the plane of polarization is twisted round; showing that the electric current changes the condition of the glass, as it would change that of iron under the same circumstances. The effect of the electric current upon the glass is however shown in nothing else than its action upon polarized light.

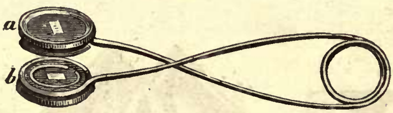
In polarized light we have a most delicate means of examining the molecular condition of a transparent body, since it reveals the slightest change in this condition, and also tells us whether or not the substance is crystalline in structure.

137. *The Tourmaline Pincette.* — The colors exhibited by polarized light are exceedingly beautiful. The simplest and most convenient apparatus for showing these colors is given in Figure 111, and is called the *tourmaline pincette.* It consists of two tourmaline plates cut parallel to the axis, mounted as shown in the figure. The plates are so arranged that they can be turned round and inclined to each

Fig. 110.

M

Fig. 111.



other at any angle. The plate to be examined is fastened to the centre of a cork disc *M* (Figure 110), and then placed between the tourmalines. The pincette is then held before the eye in diffused daylight. The tourmaline farthest from the eye acts as a polarizer, and the other as an analyzer.

SUMMARY.

When a ray of light passes through a crystal of Iceland spar it is usually *doubly refracted*, one of the refracted rays being called the *ordinary*, and the other the *extraordinary* ray.

When a doubly refracting crystal converts both portions into extraordinary rays, it is called a *biaxial* crystal. (124.)

The ordinary and extraordinary rays can be separated by a *doubly refracting prism.* (125.)

Both the doubly refracted rays have acquired *sides*, and are said to be *polarized.* They are polarized in planes at right angles to each other. (126.)

Polarization shows that light is propagated by *transverse* vibrations; and that in ordinary light these vibrations are executed in every plane, while in polarized light they are executed in only one plane. (127.)

Tourmaline absorbs one of the polarized rays. (128.)

Light may be polarized by *reflection*, and by *single refraction.* (129.)

The polariscope consists of a polarizer and an analyzer. (130.)

Nicol's prism is constructed so as to shut out one of the polarized rays. (131.)

Polarized rays can *interfere* so as to destroy each other only when they are polarized in the same plane; but they may interfere so as to produce *circular*, *elliptical*, and *rotatory* polarization when they are polarized in different planes. (132–134.)

When crystalline plates are examined in polarized light by means of an analyzer, they exhibit *interference rays.* (135.)

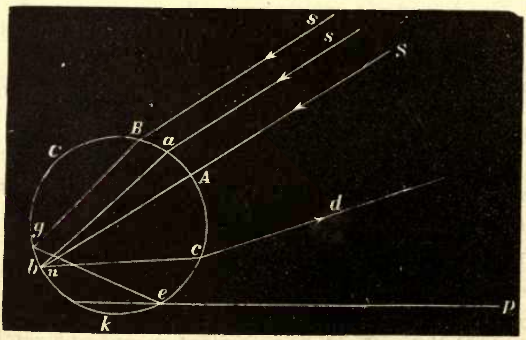
Polarized light affords an excellent means of examining the molecular condition of bodies. (136.)

THE RAINBOW.

138. *The Appearance of the Rainbow.* — The rainbow, in its most perfect form, consists of two colored arches projected upon falling rain upon which the sun is shining from the opposite quarter of the heavens. The lower or inner arch is called the *primary* bow; the upper or outer, the *secondary* bow. Each contains all the colors of the spectrum, but the order of the colors in one is the reverse of that in the other. Red is outermost in the primary bow, and innermost in the secondary. The primary bow is the narrower and brighter of the two, and when it is of unusual brightness narrow red arches are seen just within it, called *supernumerary* bows. These are sometimes three or four in number, but they can be traced only a short distance. The common centre of the bows is in a line drawn from the sun through the eye of the observer.

139. *The Cause of the Rainbow.* — The rainbow is produced by the refraction and reflection of the sunlight within the rain-drops. Its colors are due partially to the dispersion, and partially to the interference of the light

Fig. 112.

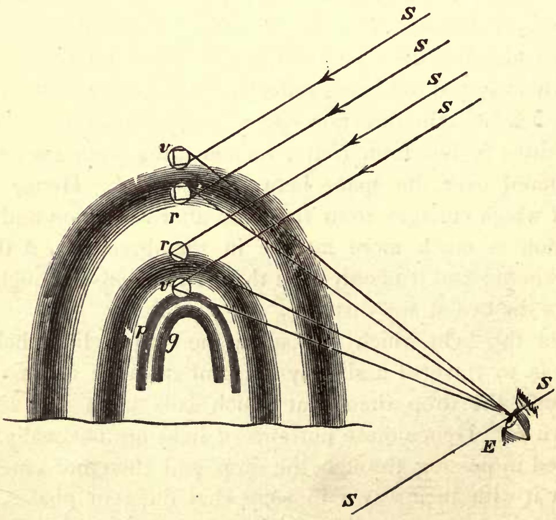


thus refracted and reflected. Let the circle in Figure 112 be a drop of rain. A ray of sunlight *S A* which passes through the centre of the drop will not be refracted, since it meets the surface of the drop perpendicularly; and the portion of it reflected at *n* will be thrown directly back. As we pass from *A* to *a* the rays become refracted more and more, since they meet the surface of the drop more and more obliquely, and, on being reflected from the inner surface of the drop, emerge in directions differing more and more from *A S*. The ray *s a* takes the direction *a b c d;* the ray *s B*, the direction *B g e p*. As we pass beyond *B* the rays are refracted so much that they begin to fall below *g*, and continue to fall farther and farther below it until we come to *C*, where the rays begin to pass by the drop. Hence all the light which falls upon the drop between *A* and *C* is refracted upon the inner surface between *g* and *n*. The light which falls upon the drop for a considerable distance each side of *B* is refracted very nearly to *g*, and, on being reflected, emerges from the drop very nearly in the direction *e p;* while the rays falling upon the drop farther from *B* are, on emerging from the drop, scattered over the space between *e* and *A*. Hence the light which emerges from the drop after refraction and reflection is much more intense in the direction *e p* than elsewhere; and it is only here that it is intense enough to affect the eye at any distance.

But the light which falls upon the drop a little below *B* has to traverse a slightly different distance in passing through the drop than that which falls upon it a little above *B*. Hence these portions of light are unequally retarded in passing through the drop, and therefore emerge from it with their waves in somewhat different phases, so that they are in a condition to interfere. Since the different-colored rays are differently refracted in passing through the drop, the direction *e p* in which the light emerges with the greatest intensity is not the same for the different colors. For red light the direction *ep* differs from that of *A S*, or of the sun's rays, by an angle of about 42°; while for violet light these directions differ by an angle of about 40°. For the other colors the difference of direction is intermediate between these two.

As the emerging rays of each of the colors are in a condition to interfere, they will of course give rise to colored bands separated by dark spaces. Let us consider the first bright band of each color. Suppose a person is looking at rain-drops illumined by the sun when near the horizon. Wherever he can direct his eye so that a line drawn from it to a rain-drop shall make an angle of 42° with a line drawn from the same drop to the sun, as at *r* in Figure 113,

Fig. 113.



he will see a band of red light; and since the drops are spread out over all the space before him, and since the sun's rays are all parallel, this band will evidently be continuous, and will have the form of an arc of a circle. The centre of this arc will lie in a line drawn from the sun through the eye of the observer, and its radius will be 42°. Whenever he can see a drop, as at *v*, such that a line drawn from his eye to it shall make an angle of 40° with a line drawn from the drop to the sun, he will see a band of violet light. This band also will have the form of an arc of a circle whose radius is 40°, and whose centre is the same as that of the red arc. Between these two bands will be seen the bands of the other prismatic colors.

The first band of each of the other prismatic colors is situated between the first and second bright bands of the red light; while the second band of each of these colors falls outside of the first violet band. This is the reason of the purity of the colors of the rainbow. The second band of each of the colors is much feebler than the first, seldom bright enough to be visible. When bright enough to be visible, they form the supernumerary bows *p g*.

The outer bow is caused by the rays which meet the eye after being twice reflected within the rain-drop, as seen at r' and v'. It is owing to this double reflection that the colors are feebler than, and in the reverse order of those in the primary bow, where the light is reflected but once.

SUMMARY.

The rainbow is seen opposite the sun.

It contains all the colors of the spectrum, the red being outermost in the primary bow and innermost in the secondary. (138.)

The rainbow is produced by the refraction and reflection of light within the rain-drop.

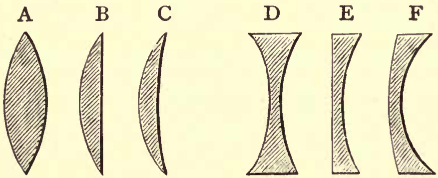
The colors of the bow are due partly to dispersion, and partly to interference. (139.)

OPTICAL INSTRUMENTS.

LENSES.

140. *Forms of Lenses.* — Lenses are pieces of glass, or other transparent substance, bounded on one or both sides by a curved surface. The forms of lenses used in optical instruments are shown in Figure 114. *A* is bounded by

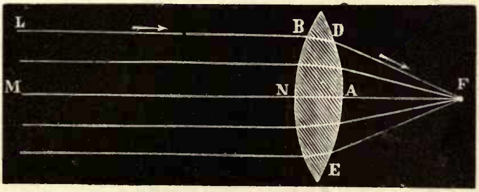
Fig. 114.



two spherical surfaces, and is called a *double-convex* lens. *B* has a spherical surface on one side, and a plane surface on the other, and is called a *plano-convex* lens. *C* has a convex surface on one side, and a slightly concave surface on the other, and is called a *meniscus*, from a Greek word meaning a *crescent*. *D* has two concave surfaces, and is called a *double-concave* lens. *E* has a concave and a plane surface, and is called a *plano-concave* lens. *F* has a concave surface on one side and a slightly convex surface on the other, and is called a *concavo-convex* lens.

Allow a beam of sunlight to fall upon a double-convex lens in a darkened room. On leaving the lens, the rays will converge to a point, called the *focus* (the Latin word for *fireplace*), since the heat as well as the light is concentrated there. This action of the lens upon the light will be understood from Figure 115. It will be seen that the section of the lens is like that of two prisms placed back to back; and it will be remembered that a ray of light, in passing through a prism, is bent twice in the same direction. The rays falling upon the upper part of the lens will be bent downward, and those falling on the lower

Fig. 115.

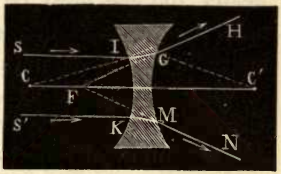


part will be bent upward, and they will all meet at *F*.

If a beam of sunlight be allowed to fall on a plano-convex lens or a meniscus, the rays will also be converged to a focus.

If, however, we use any one of the *concave* lenses, it will be found that the rays of light, instead of converging, are made to diverge, on leaving the lens. The reason of this divergence will be evident from Figure 116.

Fig. 116.



Since the convex lenses all cause parallel rays to converge, they are called *converging* lenses; while the concave lenses are called *diverging* lenses, since they cause parallel rays to diverge.

141. *Images formed by Lenses.* — Place a lighted candle before a double-convex lens in a darkened room, and a screen behind it. It will be found that, at a certain distance from the lens, a distinct inverted image of the candle will be formed upon the screen. Move the candle nearer the lens, and the image will become blurred, but will become distinct again on moving the screen farther from the lens. If the candle be moved away from the lens, the image becomes blurred; but it becomes distinct again when the

screen is brought nearer the lens. The nearer the candle is to the lens, the larger the image formed.

If now the lens be taken away, and one of greater convexity be used, it will be found that the candle must be brought nearer the lens in order that its image may be formed upon the screen, and the image becomes larger. The more convex the lens used, the nearer the candle must be brought to it, and the larger the image. If, on the other hand, a less convex lens be used, the candle must be put farther off, and the image becomes smaller.

Instead of using a more convex lens, we may add a second convex lens, with the same effect.

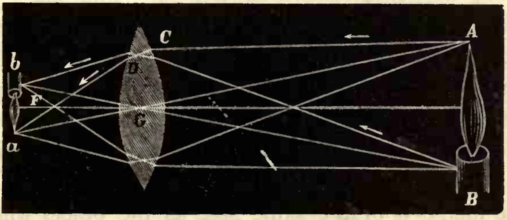
Let us suppose that the lens is made of some elastic substance, so that we may change its convexity by pulling out or pushing in its sides; and that the lens is first made very flat, so that an image is formed upon the screen when the candle is at a great distance. If we move the candle nearer, the lens must be made more and more convex, in order to keep the image on the screen distinct, and the image at the same time will grow larger and larger.

When the candle and the screen are both at the same distance from the lens, the image will be of the same size as the candle; when the candle is farther from the lens than the screen is, the image will be smaller than the candle; and when the candle is nearer the lens than the screen is, the image will be larger than the candle.

Why the image is thus formed on the screen will be evident from Figure 117. All the light which radiates from the point *A* of the candle is refracted, in passing through the lens, and concentrated at *a;* and all radiating from *B* is concentrated at *b*, and all radiating from points between *A B* will be concentrated at corresponding points between *a* and *b*. Hence the space between *a* and *b* must have the same light and shade as the flame itself, and must therefore appear exactly like it.

It will be seen that the image lies between the lines, *A a B b*, drawn from the extremities of the object through

Fig. 117.



the centre of the lens. It follows from this that the image and the object must be of the same size when they are at the same distance from the lens, and that the one which is nearer the lens must be the smaller.

The reason why the image recedes from the lens as the object approaches is also evident. As the object approaches, the rays which fall upon the lens become more and more divergent, and of course will not meet so soon on the other side of the lens.

The place where the image is formed is called the *focus* of the lens (140).

The focus of a lens, then, changes with the divergence of the rays which fall upon it. The point where parallel rays are made to meet is called the *principal focus.*

If an object were placed in the principal focus, the rays diverging from it would become parallel, on emerging from the lens. If the object were placed nearer the lens than the principal focus is, the rays would be still divergent on leaving the lens, though less so than on entering it.

SUMMARY.

There are two classes of lenses. One class causes parallel rays to converge, and the other causes them to diverge. (140.)

When objects are placed in front of a converging lens, images of them are formed at its focus behind it.

The magnitude of the image increases with its distance from the lens, and also with the convexity of the lens.

The image is of the same size as the object when it is the same distance from the lens, smaller when it is nearer the lens, and larger when it is farther from it. (141.)

THE EYE.

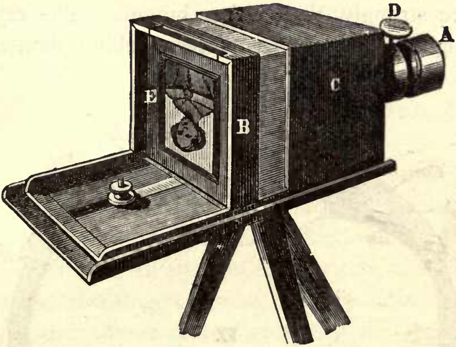
142. *The Camera Obscura.* — If a converging lens be placed before an opening in the shutter of a darkened room, a small and beautiful picture of the landscape will be seen upon a screen placed a short distance behind the lens. In this picture every motion of the branches and leaves of the trees and all other objects will be exactly delineated. An arrangement of this kind by which images of external objects are formed upon a screen in a darkened room is called a *camera obscura.*

Figure 118 represents the camera used by photographers. *C* is a dark chamber; *E* is the screen of ground glass upon which the image is received; *A* is a tube containing the combination of lenses used to form the image. This camera can be adjusted to objects at different distances by changing the position of the screen, or of the lenses (which may be moved by the screw *D*), or both.

In the ordinary camera the image is smaller than the object, since it is nearer the lens.

Any transparent substance with convex surfaces, placed

Fig. 118.

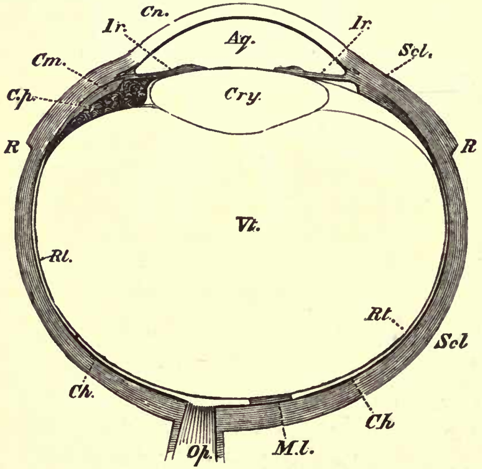


in a medium less refractive than itself, causes the rays of light traversing this medium to converge to a focus. If a watch-glass be fitted into the side of a box, and the box be filled with water, a candle may be placed at such a distance in front of the watch-glass that an image of its flame shall be formed on the opposite wall of the box. If now a convex lens of glass be introduced into the water in the path of the rays, it will cause them to come to a focus sooner, because glass refracts light more strongly than water does. An arrangement like the above might be called a *water camera.*

143. *The Eye a Water Camera.* — The eyeball is composed, in the first place, of a tough, firm, spherical case, *Scl* (Figure 119). The greater part of this case is white and opaque, and is called the *sclerotic* coat, or the *white* of the eye. In front this case becomes transparent, and is called the *cornea, Cn.* The cornea is more convex than the sclerotic. This case of the eye is kept in shape by being filled with fluids called the *humors.* One of these, the *aqueous* humor, *Aq*, fills the corneal chamber; and the other, the *vitreous* humor, *Vt*, the sclerotic chamber. The two humors are kept separate by the double-convex *crystal-*

line lens, *Cry*, which is denser, and capable of refracting light more strongly, than either humor. The crystalline lens is highly elastic, more convex behind than in front,

Fig. 119.



and is kept in place by a delicate but very strong and elastic ligament which extends from the edge of the lens to what are called the *ciliary processes* of the *choroid coat*. This choroid coat, *Ch*, is of a dark color and highly vascular (that is, full of vessels), and it lines the whole inner chamber of the eye. When it reaches the front part of the chamber, its inner surface becomes raised into longitudinal ridges with rounded ends. These ridges are the *ciliary processes*, *C. p*.

The *iris*, *Ir*, is a curtain with a round hole in the middle called the *pupil*. The iris has two sets of muscular fibres; one circular and the other radiating. By the action of these the pupil is enlarged or contracted. It is the iris which gives the *color* to the eye; and hence its name.

The *optic nerve*, *Op*, enters the back of the eye a little way from the centre towards the nose. It then spreads out over the choroid coat, forming the *retina*, *Rt*.

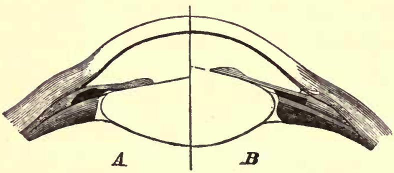
The eyeball is thus seen to be a water camera. The cornea answers to the watch-glass; the sclerotic, to the box; the humors, to the water; and the crystalline lens, to the glass lens.

In an ordinary camera it is found desirable to have what is called a *diaphragm*, to moderate the light, and to cut off all the rays except those which fall on the central part of the lens. In the eye the iris acts as a diaphragm, and has the advantage of being self-regulating. It dilates the pupil and admits more light when the illumination is too weak; it contracts the pupil and cuts off a part of the light when there is too much of it.

144. *The Adjustment of the Eye.* — That the eye must adjust itself in order to see distinctly at different distances is shown by the following simple experiment. Stick two stout needles into a piece of wood, so that one of them, *a*, shall be about six inches from the eye, and the other, *b*, about twelve, very nearly in the same direction. If now you look at the needle *b*, you will see it distinctly and without the least sense of effort; but the image of *a* will be blurred. Try now to make this blurred image of *a* distinct, and you find that you can do it, but not without effort. In proportion as *a* becomes distinct, *b* becomes blurred, and no effort will enable you to see both distinctly at the same time.

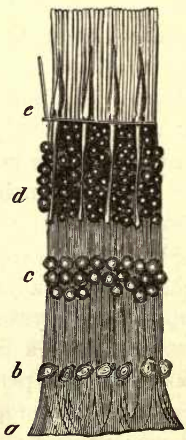
Very many explanations have been given of this remarkable power of adjustment possessed by the eye. It is only within a few years that it has come to be clearly understood. When a lighted taper is held near and a little to one side of a person's eye, any one on looking into the eye from the proper position will see three images of the flame; one reflected from the cornea, one from the front surface of the crystalline lens, and one from its rear surface. Suppose now the person's eye be steadily fixed on a distant object, and then adjusted to a nearer one in the same direction. The position of the eyeball of course remains the same. It is also found that the images reflected from the cornea and from the rear surface of the lens remain unchanged; while the image reflected from the front surface of the lens changes its position and size in such a way as to show that this surface has been brought forward and at the same time made more convex. The eye then adjusts itself to different distances by altering the convexity of the crystalline lens. This change in the form of the lens is shown in Figure 120. The half *A* shows the form of the lens when the eye is adjusted for distant objects; and the half *B*, when it is adjusted for near objects.

Fig. 120.



145. *The Structure of the Retina.*—Figure 121 represents a portion of the retina highly magnified, since the whole thickness of this membrane does not exceed the $\frac{1}{80}$ of an inch. The inner side *a*, which is in contact with the vitreous humor, is lined with what is called the *limiting membrane.* Externally and next to the choroid coat it consists of a great number of minute rod-like and conical bodies, *e*, arranged side by side. This is the *layer of rods and cones*, and occupies a quarter of the whole thickness of the retina. From the

Fig. 121.



inner ends of the rods and cones very delicate *radial fibres* spread out to the limiting membrane. *d* and *c* are *layers of granules.* The fibres of the optic nerve are all spread out between *b* and *a*. At the entrance of the optic nerve, the nerve fibres predominate, and the rods and cones are wanting. Exactly at the centre of the back of the eye there is a slight circular depression of a yellowish hue, called the *macula lutea*, or *yellow spot.* In this spot the cones are abundant without the rods and nerve fibres.

146. *The Action of Light on the Optic Nerve.* — The distribution of the nerve fibres over the front surface of the retina would seem to indicate that they are directly acted upon by the light; but this is not the case. The fibres of the optic nerve are in themselves as blind as any other part of the body. To prove this we have only to close the left eye and with the right look steadily at the cross on this page, holding the book ten or twelve inches from the eye.

The black dot will be seen quite plainly as well as the cross. Now move the book slowly towards the eye, which should be kept fixed on the cross. At a certain distance the dot will suddenly disappear; but on bringing the book still nearer it will come into view again. Now it is found upon examination that when the dot disappears its image falls exactly upon the point where the optic nerve enters the eye, and where there are no rods and cones, but merely nerve fibres. Again, the *yellow spot* is the most sensitive part of the retina, though it contains no nerve fibres.

It would appear, then, that the fibres of the optic nerve are not directly affected by the vibrations of the ether, but only through the rods and cones. This view is confirmed by the following experiment. Go into a dark room with a candle which has a small bright flame, and, looking towards the dark wall, move the light up and down close to the outer side of one eye, so that the light may fall very obliquely upon the retina, and you will see one of what are called *Purkinje's figures*. This is a vision of a series of diverging branched red lines on a dark field, with a sort of cup-shaped disc between two of them. The red lines are the blood-vessels of the retina, and the disc is the yellow spot. As the candle is moved up and down, the red lines shift their position, as shadows do when the light which casts them changes its place. Now as the light falls on the inner face of the retina, and the images shift their position as it moves, whatever perceives these images must lie on the other or outer side of the vessels which gave rise to the images. But the fibres of the optic nerve lie in front of the retina *among* these vessels; and the only parts of the retina which lie behind the vessels are the granular layers and the rods and cones.

Thus it would appear that these remarkable bodies, set upon the inner surface of the retina with their ends turned towards the light, are like so many finger-points, endowed with a touch delicate enough to feel the luminous vibrations and convert them into impulses which can excite the optic nerve; just as the otoliths and the fibres of Corti in the ear catch and convert the vibrations of the fluids of the ear into impulses which can excite the auditory nerve.

147. *The Sensation of Light may be excited by Other Causes.* — The sensation of light may be excited by anything which can excite the optic nerve. Thus an electric shock sent through the eye gives rise to an apparent flash of light. If a small piece of zinc be held in the mouth, and one end of a silver pencil-case be held in the corner of the eye, a flash is seen when the silver and the zinc are brought in contact. If the finger be pressed on one

side of the eyeball, a luminous image is seen. In the same way a blow on the head sometimes makes one "see stars."

148. *The Duration of the Impression on the Retina.* — The impression made by light on the retina does not cease the instant the light is removed, but lasts about the eighth of a second. If luminous impressions are separated by a less interval, they appear continuous. Thus, if a stick with a spark of fire at the end be whirled round rapidly, it gives the impression of a circle of light. The spokes of a carriage wheel in rapid motion cannot be distinguished.

The optical toy called the *thaumatrope* illustrates the same principle. It consists (Figure 122) of a cylindrical paper box made to rotate on an upright axis. Near the top of the box is a row of upright slits. The successive positions which a moving body assumes are represented in order upon a strip of paper; and this paper is put within the box, which is then whirled round rapidly. If we look at the figures through the slits, the successive positions come before the eye one after another, and the impression of each lasts till the next arrives, so that they all blend into one, and the object appears to be really going through the evolutions represented.

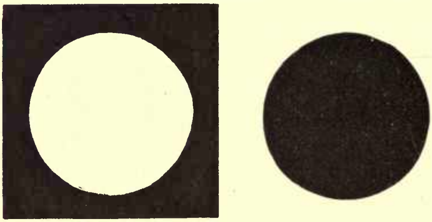
Fig. 122.

149. *Irradiation.* — When a white or very bright object is seen against a black ground it appears larger than it really is; while a black object on a white ground appears smaller than it really is. The two circles given in Figure 123 illustrate this. The black one and the white one have just the same diameter.

This effect is called *irradiation.* It arises from the fact that the impression produced by a bright object on the retina extends beyond the outline of the image. It bears the same relation to the space occupied by the image as the duration of the impression does to the duration of the image.

We have one of the most marked cases of irradiation in

Fig. 123.



the moon when a few days old. The new moon seems much larger than the old one which it is said to "hold in its arms.".

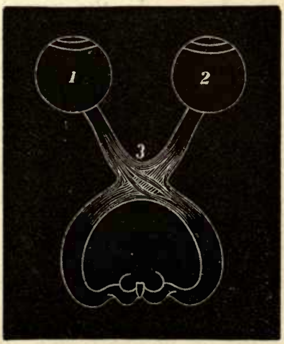
150. *The Sensibility of the Retina is easily exhausted.* — When we look at a bright light, and then turn the eye towards a moderately lighted surface, a dark spot is seen; showing that the part of the retina on which the bright light fell has lost for the moment its sensibility, or become blind. If the bright object be of one color, the part of the retina on which its image falls becomes insensible to rays of that color, but not to those of other colors. This explains the appearance of what are called *complementary* colors. For example, if a red wafer be stuck upon a sheet of white paper, and viewed steadily for some time with one eye, and then the eye be turned to another part of the paper, a greenish spot will appear of the size and shape of the wafer. The red image has made the retina blind to red light, but it has left it sensitive to the remaining colors which make up white light; and when red is taken from white light the combination of the other colors gives a greenish hue. If the wafer had been green, the spot seen would have been red.

151. *Color-Blindness.* — In some persons the retina appears to be affected in one and the same way by different colors, or even by all colors. The most common form of this *color-blindness*, as it is called, is an inability to distinguish red and green. Thus many persons cannot distinguish between the colors of the leaves of the cherry-tree and its fruit. In some cases, persons who were thus color-blind without being aware of it, and who have been employed on railways, have mistaken the color of signal lights, and serious accidents have been the result.

This blindness may arise either from a defect in the retina, or from some peculiarity in the absorptive powers of the humors of the eye.

152. *Single Vision.* — Since an image is formed on the retina of each eye, it would seem that we ought to see objects double. That we see them single is probably owing to the way in which the eyes are connected with each other and with the brain. This connection is shown in Figure 124. It will be seen that a part of the optic nerve runs round from one eye to the other, and a part from each eye to each side of the brain, and a part from one side of the brain round to the other. Each eye is thus connected with the other, and with each side of the brain, and these sides are connected with each other. In this way the eyes are virtually a single eye, the inner side of the one corresponding to the outer side of the other; that is, each point to the left of the middle of one eye corresponds to a point situated the same distance to the left of the middle of the other. As the images

Fig. 124.



are always formed with their centres at the centres of the eyes, the right and left parts of the images will be on corresponding parts of the eyes, and they will therefore appear as one.

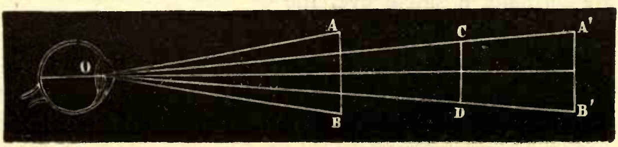
If, however, by pressing the finger upon the eyeball, or in any other way, we cause the images to fall upon parts of the eye which do not correspond, the object is seen double. Some persons always see double, because they cannot direct both eyes so that the image of an object shall be formed about the centre of each.

153. *The Optical Axis and the Visual Angle.* — A line drawn from the centre of the yellow spot through the centre of the pupil is called the *optical axis.* When we look at any object we must turn the eye so as to direct this axis toward it. This enables us to appreciate the *direction* of the object.

We have seen that the image of a candle or other object, formed by a convex lens, is contained between lines drawn from the extremities of the object through the centre of the lens. In the same way the image of an object on the retina is contained between lines drawn from the extremities of the object through the centre of the crystalline lens. The angle contained between lines thus drawn is called the *visual angle* of the object, and of course measures the length of the image on the retina. All objects which have the same visual angle form images of the same length on the retina.

154. *How we estimate the Size of a Body.* — The visual angle evidently gives us no information as to the real size

Fig. 125.

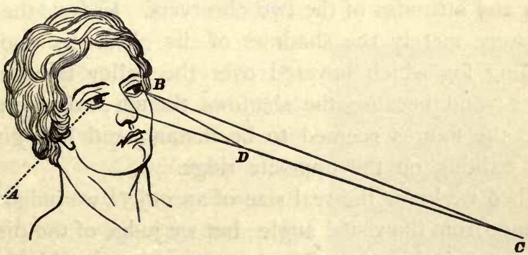


of a body; for we see from Figure 125 that the visual angle of a body diminishes as its distance increases, and also that bodies at different distances may have the same visual angle, though they are not of the same size. Thus *A B* and *A′ B′* are the same object, but *A′ B′* which is farther off has the smaller visual angle. Again *C D* and *A′ B′* have the same visual angle, but *A′ B′* is the larger.

We must, then, know the distance of a body in order to estimate its size; but when we know this distance we estimate its size instinctively. Thus a chair at the farthest end of the room has a visual angle only half as large as a chair at half the distance, yet we cannot make it seem smaller if we try. If we are in any way deceived as to the distance of an object we are also deceived as to its size.

155. *How we estimate the Distance of an Object.* — If we refer to Figure 126, we see that when the eyes are directed

Fig. 126.



to a distant object, as *C*, they are turned inward but slightly; while they are turned inward considerably when directed to the nearer object *D*. The muscular effort we have to make in thus turning the eyes inward so as to direct them upon an object is one of the best methods we have of estimating its distance.

Again, we have seen that we have to adjust the eye for different distances, and the effort we have to make in this adjustment helps us to judge of the distance.

We also judge of the distance of an object from the distinctness with which we see it. The more obscure it is, the more distant it seems. It is for this reason that objects seen in a fog sometimes appear enormously large. They appear indistinct, and we cannot rid ourselves of the impression that they are far off; and hence they seem large, though they may really be small and near us.

The celebrated "Spectre of the Brocken," seen among the Hartz mountains, is a good illustration of the effect of indistinctness upon the apparent size of an object. On a certain ridge, just at sunrise, a gigantic figure of a man had often been seen walking, and extraordinary stories were told of him. About the year 1800 a French philosopher and a friend went to watch the spectre. For many mornings they looked for it in vain. At last, however, the monster was seen, but he was not alone. He had a companion, and, singularly enough, the pair aped all the motions and attitudes of the two observers. In fact, the spectres were merely the shadows of the observers upon the morning fog which hovered over the valley between the ridges; and because the shadows, though near, were very faint, the figures seemed to be distant, and like gigantic men walking on the opposite ridge.

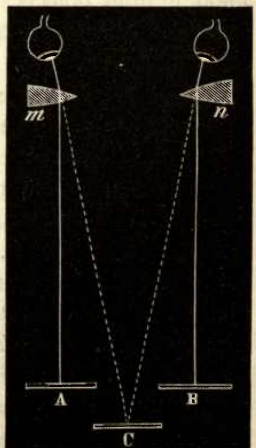
When we know the real size of an object we judge of its distance from the visual angle; but we judge of the distance of unknown objects mainly by comparing it with the distance of known objects. This is one reason why the moon appears larger near the horizon than overhead, though she is really nearer in the latter case. When she is on the horizon we see that she is beyond all the objects on the earth in that direction, and therefore she seems farther off than when overhead, where there are no intervening objects to help us to judge of the distance.

We are better able to judge of the distance of objects seen horizontally on the surface of the earth, where we are in the habit of walking about, than when we see them above us. In the latter case they seem nearer and consequently smaller than they really are. Thus the vane on a church spire, a hundred feet high, may be five or six feet long, but it does not appear half that length. Again, people on the top of a lofty building appear very small, while at the same distance from us on the surface of the earth they would appear of the ordinary size.

156. *Why Bodies near us appear Solid.* — Hold any solid object, as a book, about a foot from the eyes, and look at it first with one eye and then with the other. It will be seen that the two images of the object are not exactly alike. With the right eye we can see a little more of the right side of the object, and with the left eye a little more of its left side. It seems to be the blending of these two pictures which causes objects to appear solid.

157. *The Stereoscope.* — The principle just stated explains the action of the *stereoscope.* Two photographs of an object are taken from slightly different points of view, so as to obtain pictures like those formed in the two eyes. These photographs are placed before the eyes in such a manner that each eye sees only one, but both are seen in the same position. This is effected by the arrangement shown in Figure 127. The pictures are placed at *A* and *B*. The rays of light from them fall upon the lenses *m* and *n*, and in passing through them are bent so that they enter the eye as if

Fig. 127.

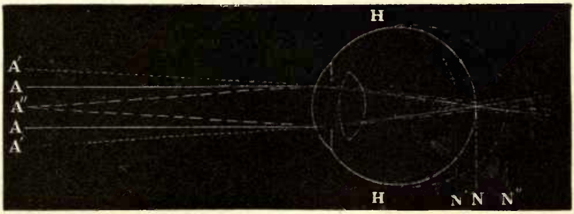


they came from the direction *C*. The lenses are portions of a double-convex lens, arranged as shown in the figure.

158. *The Laws of Distinct Vision.* — To see an object distinctly, a clear image of it must be formed on the retina. It has been seen that the eye has the power of adjusting itself so as to form distinct images of objects at different distances. When, however, an object is brought quite near the eye, it becomes indistinct; showing that there is a limit to this power of adjustment. The rays are now so divergent that the lens cannot bring them to a focus on the retina. The nearest point at which a distinct image is formed upon the retina is called the *near point* of vision, and the greatest distance at which such an image is formed is called the *far point*. In perfectly formed eyes the near point is about 3½ inches from the eye, and the far point is infinitely distant. In such eyes parallel rays are brought to a focus exactly at the retina when the eye is at rest; that is, when the crystalline lens is of its natural convexity. The pupil of the eye is so small that the rays which fall upon it from objects 18 or 20 inches distant diverge so little that they may be regarded as parallel. The distance of the near and far points, however, is not the same for all eyes. In some cases, the near point is considerably less than 3½ inches from the eye, while the far point is only eight or ten inches. In other cases the near point is twelve inches from the eye, and the far point infinitely distant. The former are called *near-sighted* eyes; the latter, *far-sighted* ones.

It was once thought that near-sightedness was due to the too great convexity of the cornea or the crystalline lens, or of both, and far-sightedness to the too slight convexity of the same. But actual measurement has shown that their real cause lies in the shape of the eyeball, which in far-sighted people is flattened, and in near-sighted people elongated, in the direction of the axis. In Figure 128 the curve N shows the form of the *normal*, or perfect eye;

Fig. 128.



N', of the far-sighted eye; and N'', of the near-sighted eye. In this figure the eye is represented as at rest, and it is seen that the parallel rays A and A are brought to a focus on the retina of the normal eye, while only the convergent rays A' and A' are brought to a focus on the retina of the far-sighted eye, and only the divergent rays A'' on the retina of the near-sighted eye.

A'' then is the far point for the near-sighted eye, since the lens has now its least convexity; and this point must be within 18 or 20 inches, since the rays from an object at a greater distance are virtually parallel and cannot be brought to a focus on the retina. The *near* point must be less than for the normal eye, since the retina is farther from the lens, and therefore rays of greater divergence can be brought to a focus upon it. In the far-sighted eye the retina is nearer the lens than in the normal eye; hence the near point must be farther away. While then the normal eye sees distant objects distinctly without adjustment, the far-sighted eye must adjust itself to see such objects.

The defect of far-sighted eyes can be in great measure remedied by wearing convex glasses, which help to bring the rays to a focus on the retina, and thus diminish the distance of the near point. The defect of near-sighted eyes can be remedied by the use of concave glasses, which render parallel rays divergent, and thus increase the distance of the far point.

The first law of distinct vision, then, is that *a distinct image of the object must be formed on the retina.*

Again, it is well known that, as evening approaches, objects become indistinct. Here, of course, the image formed on the retina is distinct, but it is not brilliant enough to produce the proper effect upon the optic nerve.

The second law of distinct vision, then, is that *the image must be sufficiently illuminated.*

Again, some objects are so small that they cannot be seen, however much they may be illumined. Here the image is too minute to affect the optic nerve.

The third law of distinct vision, then, is that *the image must be of sufficient magnitude.*

159. *Old Eyes.* — As the eye grows old it loses its power of adjustment, the crystalline lens becoming less elastic. Hence old eyes can see distinctly only distant objects. This, however, is quite a different thing from far-sightedness. In the far-sighted eye there is no lack of power to change the convexity of the lens, but this power becomes useless because of the distance of the retina.

This defect of vision caused by age can be remedied by the use of convex glasses.

SUMMARY.

The *camera obscura* is an apparatus by which an image of an object can be formed on a screen in a darkened chamber.

The chamber may be filled with air, water, or any other transparent substance. (142.)

The *eye* is a *water camera.* (143.)

The eye adjusts itself to light of varying intensity by varying the size of the pupil. (143.)

It adjusts itself to various distances by changing the convexity of the crystalline lens. (144.)

The *optic nerve* is *blind.*

The luminous vibrations are intercepted by the *rods and cones*, and by these transmitted to the optic nerve. (146.)

Anything which excites the optic nerve produces the sensation of light. (147.)

The impression on the retina lasts an appreciable time after the object which produced it has been removed. (148.)

The impression of a bright object extends beyond the image, giving rise to *irradiation.* (149.)

The sensitiveness of the retina for any color is readily exhausted. (150.)

Many people are *color-blind.* (151.)

The eyes are so connected by the optic nerve that we see objects single, though an image is formed on each retina. (152.)

We judge of the direction of an object by the direction of the axis of the eye when turned towards it.

The *visual angle* of an object depends on its size and distance. (153.)

We judge of the size and distance of an object by means of its visual angle, the direction of the optical axes, the distinctness of the image, and the effort we have to make to adjust the eye for seeing it. (154, 155.)

Near bodies seem *solid,* because the images in the two eyes are not exactly alike. (156.)

The *stereoscope* causes pictures on a plane surface to appear solid. (157.)

In order that vision may be distinct, a distinct image must be formed on the retina, the image must be sufficiently illuminated, and must have sufficient magnitude.

Perfect eyes can adjust themselves to any distance from $3\frac{1}{2}$ inches to infinity.

Near-sighted eyes can adjust themselves only to short distances, and far-sighted eyes only to long distances. (158.)

Eyes lose their power of adjustment as they grow old. (159.)

Near-sightedness and far-sightedness are due to defective forms of the eyeball. These defects and that caused by age can be partially remedied by the use of glasses. (158, 159.)

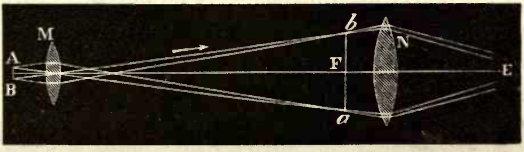
THE MICROSCOPE AND THE TELESCOPE.

160. *The Simple Microscope.* — We have seen that an object must form upon the retina an image of a certain magnitude, in order to be distinctly seen. Now the magnitude of the image may be increased indefinitely by bringing the object nearer the eye; but when it is brought too near, the eye is not able to bring the rays from it to a focus on the retina. We may accomplish this, however, by the aid of a convex lens. Such a lens is the simplest form of a *microscope*. It is called a *microscope* (from two Greek words meaning *to see small things*) because it enables us to see things smaller than the unaided eye can distinguish. The more convex the lens, the nearer can the object be brought to the eye, and the larger will be the image on the retina.

161. *The Compound Microscope.* — In Figure 129 we have what is called a *compound* microscope. *M* is a lens; *A B* is an object placed near it. An enlarged image of *A B* is formed at *a b*, and this image is viewed through the lens *N*, in the same way that an object is viewed with the single lens of a simple microscope.

The greater magnifying power of this microscope is due to the fact that we examine, not the object itself, but an enlarged image of it.

Fig. 129.



The lens *M* is called the *object-glass* or the *objective;* and *N*, the *eye-piece*. The latter is usually a combination of two lenses.

We have seen that a convex lens causes the rays passing through it to meet at a point called the *focus*. In reality, however, this focus is not exactly the same for all the rays. Those falling near the margin of the lens meet a little sooner than those falling upon its centre, giving rise to what is called *aberration*. The more convex the lens, the greater the aberration, and the more indistinct the image.

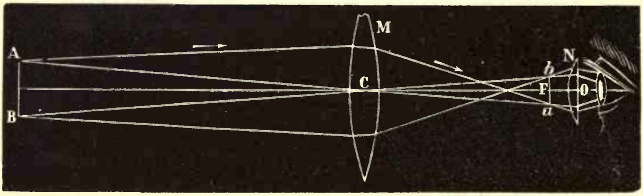
This aberration can be diminished by diminishing the size of the lens, so that all the rays must fall near its centre. For this reason the objective of a compound microscope, which is a very convergent lens, is made very small.

The magnifying power of a microscope is commonly expressed in *diameters*. If it makes the breadth of the object appear 50 times as great as it really is, it is said to magnify 50 diameters. Of course the surface of the object is increased as the square of its diameter; or in this case 2,500 times. The most powerful compound microscopes magnify 1,500 diameters, or even more.

Of course there is no more light on this enlarged image than there is on the object itself; hence the object must be very strongly illuminated in order that the light when thus diluted may be sufficient to affect the eye.

162. *The Telescope.* — As an object is moved farther and farther from the eye, its image becomes smaller and smaller, until at last it may cease to affect the eye, even though the object itself may be very large. An instrument for examining distant objects is called a *telescope.* Its essential parts are shown in Figure 130. The word is

Fig. 130.



made up of two Greek words meaning *to see far off.* Its construction is very much like that of the compound microscope. It has an *object-glass* for forming an image of the object, and an *eye-piece* for examining this image. It differs from the microscope mainly in the fact that the image is always smaller than the object. Since the object is very distant, the rays which fall upon the object-glass are virtually parallel, and, therefore, this glass may have a great diameter without making the image indistinct through aberration. The larger the diameter the better, since it will collect and concentrate the more light on the image. The object-glass of the great telescope in the Observatory at Cambridge, Mass., is 15 inches in diameter. The telescope in the Observatory at Chicago, Illinois, has an object-glass 18 inches in diameter. This instrument was made by Alvan Clark & Sons of Cambridge, and is considered the best telescope in the world. Such an instrument takes in as much light as the eye would if its pupil were 18 inches in diameter; that is, since the pupil of the eye is not more than a quarter of an inch in diameter, $(4 \times 18)^2$ times as much light.

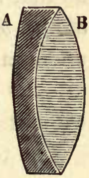
The size of the image increases with its distance from the object-glass. That this distance may be as great as possible, the object-glass has very slight convexity.

We now see how the object-glass of the telescope differs from that of the microscope. The former is made as large as possible, with very slight convexity; while the latter is made as small as possible, with very great convexity.

The eye-piece is the same in both instruments. The magnifying is chiefly done by the eye-piece.

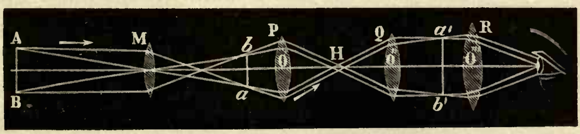
We have seen that light is dispersed when passing through a prism (100), so as to form the spectrum. Now the edge of a lens is like the refracting angle of a prism, and therefore disperses the light which passes through it, giving rise to colored fringes round the image. This can be prevented by the use of a second lens made of glass of different dispersive power. A lens thus corrected is called an *achromatic* (*colorless*) lens, and is shown in Figure 131. The second lens *A* acts just as the second prism does in Figure 75.

Fig. 13.



163. *The Terrestrial Telescope.* — Of course the image in the telescope described above will be inverted. This makes no difference when we are looking at the heavenly bodies, but is an inconvenience in viewing terrestrial objects. An erect image may be obtained by using additional lenses, as shown in Figure 132. The first inverted image is formed at *a b*. The lens *P*

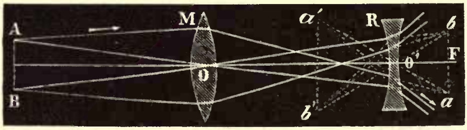
Fig. 132.



renders the rays diverging from this image parallel, and the lens *Q* brings them to a focus again at *a′ b′*. These two lenses then act as one, and form an inverted image of the inverted image, which will be an erect image.

164. *The Opera-Glass.* — The lenses used in the opera-glass are shown in Figure 133. *M* is the object-glass, and

Fig. 133.



is a converging lens. *R* is the eye-piece, and is a diverging lens. The rays of light coming from the ends *A* and *B* of the object would be brought to a focus at *a b*, where an inverted image would be formed. But on falling upon the eye-piece *R* they are turned aside, as shown in the figure, so that they enter the eye as if they came from the points *a′* and *b′*. Hence the eye sees the object *A B* erect and under a greater visual angle than if it had been viewed directly; so that the object appears larger than it would without the aid of the instrument.

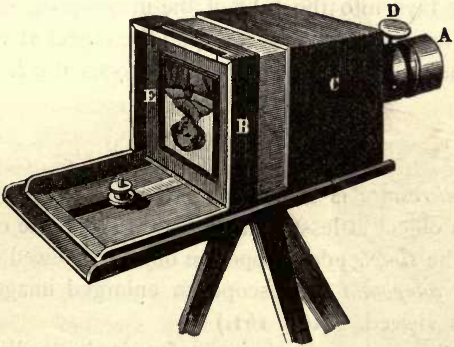
The telescope invented by Galileo was an opera-glass.

THE MAGIC LANTERN.

165. In the photographic camera (Figure 134) a small inverted image of the object is formed upon the glass screen *E*. We will now suppose this image to be a transparent picture, and that a strong light is sent through it from behind. An enlarged and upright image of the picture will be formed by the lenses in the tube *A*, and may be received upon a screen. The nearer the picture is to the lens, the farther off and the larger will be the image.

An instrument for thus projecting pictures upon a screen is called a *magic lantern*.

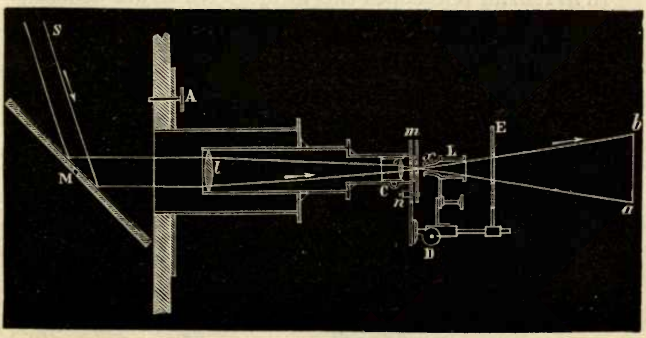
Fig. 134.



If the picture is greatly enlarged, it is necessary to use a strong light. The calcium light, the magnesium light, the electric light, and solar light are best adapted to the purpose. For small lanterns and a small screen an oil-lamp with a reflector may be used.

When the picture is very small, it must be placed very near the lens in order that a large image may be thrown

Fig. 135.



upon the screen. In this case, as in that of the compound microscope, the lens must be very small and very convex. The instrument thus arranged is called a *solar microscope*, and is shown in Figure 135. *M* is a mirror which throws the solar rays into the tube of the microscope, where the lenses *l* and *o* condense them upon the object at *m*. The small lens *x* then brings the rays to a focus at *a b*.

SUMMARY.

The *microscope* is an instrument which enables the eye to see an object at less distance than it otherwise could.

With the *simple* microscope the object is viewed directly; with the *compound* microscope an enlarged image of the object is viewed. (160, 161.)

The *telescope* is an instrument for viewing a distant object. A bright image of the object is formed in the focus of the object-glass and viewed with a microscope.

In a compound microscope the image is always larger than the object; in the telescope, it is always smaller. (162.)

The object-glass of a telescope is rendered *achromatic* by combining two lenses of different dispersive power. (162.)

In *terrestrial* telescopes two or more lenses are combined so as to make the object appear upright. (163.)

In the *opera-glass*, the object-glass is a converging lens, and the eye-piece a diverging lens. (164.)

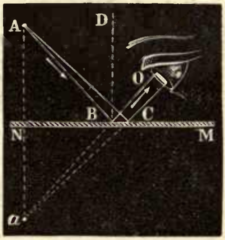
The *magic lantern* and *solar microscope* are instruments for throwing a magnified image of an object upon a screen in a darkened room. (165.)

MIRRORS.

166. *Plane Mirrors.* — Any smooth reflecting surface is called a *mirror.* If the surface is flat, it is called a *plane* mirror.

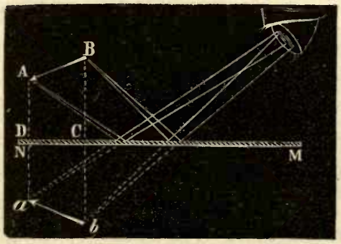
In Figure 136 suppose a point of light *A* to be in front of the plane mirror *N M*. The rays diverging from *A*, as *A B* and *A C* are reflected from the mirror so as to make the angle of reflection equal to that of incidence. After reflection they enter the eye *O* just as if they came from the point *a.* This point will therefore appear to be just as far behind the mirror as *A* is in front of it.

Fig. 136.



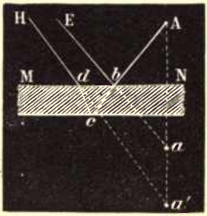
Suppose the arrow *A B* (Figure 137) to be placed in front of the mirror. The rays diverging from *A* will, after reflection, enter the eye as if they came from *a;* those diverging from *B*, as if they came from *b;* and those which come from points between *A* and *B*, as if they came from corresponding points between *a* and *b*. Hence the arrow will appear to be as far behind the mirror as it really is in front of it.

Fig. 137.



167. *Multiple Images in Plane Mirrors.* — If a light be placed in front of a looking-glass, as at *A* (Figure 138) and an observer look at it in the mirror from the direction *H*, he sees two lights, one at *a* and the other at *a′*. A part of the light is reflected from the upper

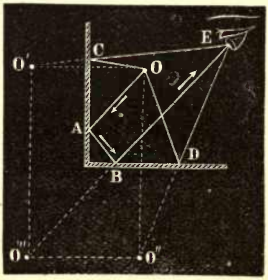
Fig. 138.



surface of the mirror in the direction *b E*, and enters the eye as if it came from *a*. Another part is reflected at *c*, and, on being refracted at *d*, enters the eye as if it came from *a'*.

If two mirrors be placed at right angles, as shown in Figure 139, and a light be placed at *O*, three images of the light will be seen. A part of the rays from *O*, reflected at *C*, enter the eye as if they came from *O'*; another part, reflected from *D*, as if they came from *O''*; and another part, twice reflected, at *A* and *B*, as if they came from *O'''*.

Fig. 139.

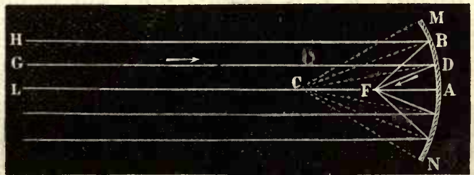


By placing the mirrors at different angles, a variety of images may be obtained. Their number and their arrangement (which will always be symmetrical) will depend upon the angle at which the mirrors are placed. The *kaleidoscope*, invented by Sir David Brewster, depends upon this effect of inclined mirrors. It consists of a tube in which there are three mirrors inclined at an angle of 60°. One end of the tube is closed with a piece of ground glass, and the other end with a cap in which there is a small opening. Small irregular pieces of colored glass are placed between the ground glass and another glass disc. On looking into the tube, these objects and their images seem arranged in beautiful and symmetrical forms, which continually change as the tube is turned round.

168. *Concave Mirrors.* — A concave mirror is a portion of a spherical surface viewed from within.

The action of such a mirror upon parallel rays is shown in Figure 140. *C* is the centre of the sphere of which the mirror is a part. The radii *C A*, *C B*, and *C D* are of

Fig. 140.



course perpendicular to the surface of the mirror at the points *A*, *B*, and *D*. The parallel rays *H*, *G*, and *L*, on meeting the mirror, are reflected so as to make the angle of reflection equal to that of incidence; that is, making *C B H* equal to *C B F*, *C D G* to *C D F*, etc. Hence the reflected rays are made to converge. If the mirror is not more than 8° or 10° in breadth, the rays will all meet at *F*, half-way between *C* and *A*. This point is called the *principal focus* of the mirror.

Fig. 141.

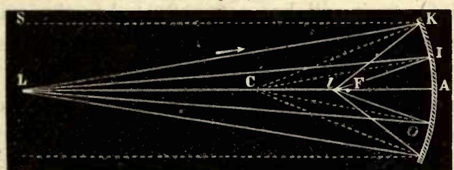
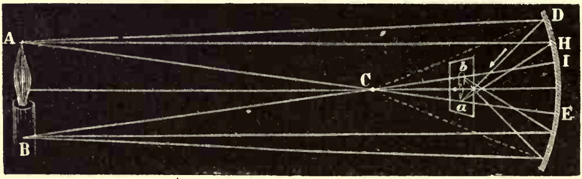


Figure 141 shows the action of a concave mirror upon diverging rays. The rays diverging from the point *L* meet the mirror at a smaller angle of incidence than if they were parallel, and their angles of reflection will also be less. They will therefore meet at a point, *l*, farther from the mirror than the principal focus is. If the luminous point were at *l*, the rays would be brought to a focus at *L*. The points *L* and *l* are called *conjugate foci*.

As *L* approaches *C*, *l* also approaches it, until at *C* the two coincide. As *L* recedes from *C*, *l* approaches *F;* until *L* is removed so far that the rays become sensibly parallel, when *l* coincides with *F*. If *L* is at *F*, the reflected rays will be parallel; if *L* is inside *F*, they will be divergent, but less divergent than on meeting the mirror.

If a candle *A B* (Figure 142) be placed before a con-

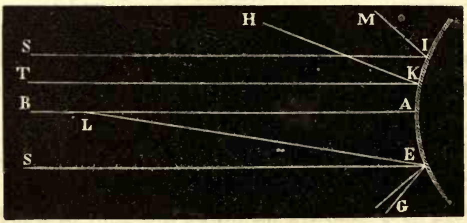
Fig. 142.



cave mirror, the rays diverging from *A* are brought to a focus at *a;* those from *B*, at *b;* and those from points between *A* and *B*, at corresponding points between *a* and *b*. So long as *A B* is to the left of *C*, the image will be smaller than the object; when *A B* is to the right of *C*, the image will be larger than the object; and in both cases it will be inverted. If, however, the candle is inside the principal focus, it will be seen reflected in the mirror, upright and enlarged, since the rays are rendered less divergent on leaving the mirror.

169. *Convex Mirrors.* — A convex mirror is a portion of the surface of a sphere viewed from without.

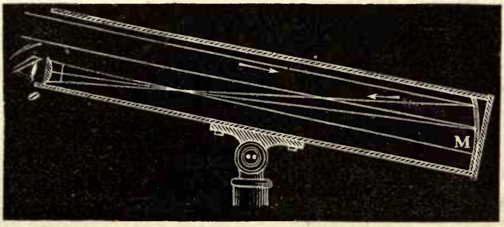
Fig. 143.



Such a mirror renders parallel rays divergent, and divergent rays more divergent (Figure 143). Hence an object reflected in it appears smaller than it really is.

170. *The Reflecting Telescope.* — A concave mirror may be used instead of the object-lens of a telescope, as is shown in Figure 144. The rays from an object falling upon the

Fig. 144.

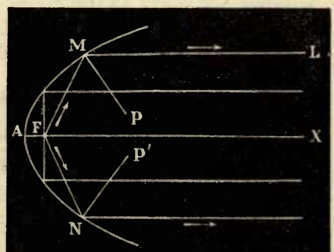


concave mirror *M* are reflected so as to form an image at the focus, and this image is viewed with the eyepiece *o*. As the image here is formed by reflected light the instrument is called a *reflecting* telescope. The ordinary telescope is called a *refracting* telescope, since the image is formed by refracted light.

The largest reflecting telescope ever made is the celebrated one of Lord Rosse, which has a diameter of 6 feet and a focal length of 53 feet.

171. *Parabolic Mirrors.* — The mirror shown in Figure 145 has what is called a *parabolic* surface, and is therefore called a *parabolic* mirror. The point *F* is called the *focus*, and the line *A X* the *axis*, of the mirror. If parallel rays be allowed to fall upon such a mirror, they are reflected exactly to the focus *F*, whatever may be the breadth of the mirror. On the other hand, if a light be placed at the focus, its rays will be reflected from the mirror in parallel lines. This is be-

Fig. 145



cause the curvature of a parabolic surface is such that if a perpendicular be drawn to any point, as *M*, the angle which it makes with the line *M L*, drawn parallel to the axis, is equal to the angle it makes with the line *M F* drawn to the focus.

Parabolic mirrors are used for the lanterns placed in front of locomotive engines and in many light-houses.

SUMMARY.

Any smooth reflecting surface is called a ***mirror.***

When the surface is flat, it is called a *plane* mirror; when it is curved, a *concave* or *convex* mirror. (166, 168.)

An object is seen reflected in a plane mirror without enlargement, but it appears as far behind the mirror as it really is before it. (166.)

In a convex mirror an object appears smaller, and in a concave mirror larger, than it really is. (168, 169.)

An inverted image of an object is formed in the focus of a concave mirror. (168.)

A concave mirror may be used in place of the object-glass in a telescope. (170.)

A parabolic mirror renders the rays which diverge from its focus parallel. (171.)

PHOTOGRAPHY.

172. *The Chemical Action of Light.* — If a surface coated with chloride or iodide of silver be exposed to light, it gradually blackens. The stronger the light, the more rapidly the change of color takes place. There are many other chemical substances which are more or less affected by the action of light. In some cases the light does not actually decompose the substance, but gives it a disposition to break up.

This chemical action of light is the basis of the art of ***photography.***

173. *The Daguerreotype.* — If the image in the camera obscura (142) be allowed to fall for a short time upon a copper plate coated with iodide of silver, and the plate be removed and examined, no change appears to have taken place. If, however, the plate be now exposed to the vapor of mercury, an image appears exactly like that formed in the camera. The mercury condenses upon those parts of the plate which have been most strongly illumined, and thus *develops* the picture which before was *latent.* If this plate were now exposed to the light, the remaining iodide of silver would blacken so as to obliterate the picture. But if the iodide be dissolved and washed off by a solution of hyposulphite of sodium, the picture is fixed. This process of obtaining pictures by means of light was discovered in 1839 by a Frenchman named Daguerre, and from him the pictures are called *daguerreotypes.*

The theory of the daguerreotype process is thus stated by Miller * : —

" Under the influence of light, the superficial layer of iodide of silver is modified so as to render it susceptible of decomposition. When the plate is acted upon by the mercurial vapor, the iodine is driven to the deeper layer of silver, and a film of silver is liberated upon the surface of those parts which have been exposed to the action of light, the thickness of this film varying with the intensity and duration of the light. The reduced silver combines with the mercury, and a film of silver amalgam is formed, which varies in thickness with the thickness of the silver film, in consequence of which the reflected tints differ according to the varying thickness of this film : those parts of the iodized plate which have not been exposed to the light of course do not combine with the mercury. After the plate has been treated with hyposulphite of sodium, the

* Elements of Chemistry (3d Edition), Part II., page 895.

excess of iodide of silver is removed, and the blacks consist of metallic silver. Experiment proves that those parts of the plate immediately beneath the highest lights are more deeply corroded than the others by the action of the iodine which has been driven inward during the process of mercurialization.

"In complete accordance with the foregoing explanation is a curious fact first pointed out by Mr. Shaw, — that if a plate, after it has received the impression in the camera, but before it has been mercurialized, be exposed to the vapor of iodine or of bromine for a few seconds, the image is completely effaced, and is no longer producible by mercury."

174. *The Collodion Process.* — This process, which is the one now almost universally employed, was invented by Mr. Archer, in 1851. A solution of gun-cotton in ether is impregnated with a small quantity of iodide of potassium or cadmium, forming what is called *iodized collodion.* A film of this is spread on a plate of glass, which is then immersed in a solution of nitrate of silver. The collodion film thus becomes coated with yellow iodide of silver, which is very sensitive to light. The plate thus prepared requires an exposure of only a few seconds in the camera to produce the *latent image*, which is afterwards developed by pouring over the surface a weak solution of pyrogallic acid mixed with acetic acid. A solution of ferrous sulphate is also often used for the same purpose. The image is now *fixed*, as described above, by pouring over the plate a solution of hyposulphite of sodium or of cyanide of potassium. The *negative* picture thus obtained can then be employed for printing a *positive*, as explained in the next section.

175. *Photographic Printing.* — In 1839 Mr. Fox Talbot of England discovered the process now known as *photographic printing.* "It consisted in soaking ordinary writ-

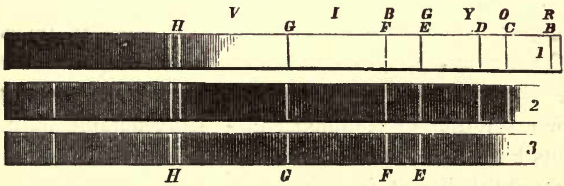
ing-paper in a weak solution of common salt, and, when dry, washing it over upon one side with a solution of nitrate of silver, consisting of one part of a saturated solution of nitrate with 6 or 8 parts of water. This operation was performed by candle-light, and the paper was dried at the fire; in this manner a film of chloride of silver, mixed with an excess of nitrate of silver, was formed upon the surface of the paper. Suppose that it were desired to obtain a copy of an engraving, or of the leaf of a tree: one of the sheets so prepared was laid under the engraving or the leaf which was to be copied; the two were pressed firmly together between two plates of glass, and exposed to the direct rays of the sun, or even to diffused daylight, for a period of half an hour or an hour. The impression thus obtained was a *negative* one, that is to say, the shadows were represented by lights, and the lights by shadows; those portions of the surface which had been exposed to the strongest light becoming dark, and the parts corresponding to the deep shadows in the engraving remaining white. The pictures were then fixed by immersing them in a strong solution of common salt. Considerable improvements have been introduced into this process since it was first published, but, in principle, this operation, which has been termed *photographic* printing, remains unchanged." (Miller.)

Of course, when *negative* pictures are copied by this process, *positive* ones (or those having the proper distribution of light and shade) are obtained.

176. *Chemical Action of the Solar Spectrum.* — If a pure solar spectrum be allowed to fall upon a sheet of sensitive paper, it will be soon seen that the chemical action is not uniformly distributed over the luminous image. The maximum of light falls in the yellow rays about Fraunhofer's line *D*, while that of chemical action occurs in the blue portion of the spectrum near the line *G*, about one third

of the way between that line and *H*. The blackening effect extends nearly to *F* in the green, while it is prolonged beyond the violet end of the spectrum a distance nearly equal to two thirds of the length of the luminous spectrum, the chemical effect gradually shading off until it is imperceptible. The maximum point, however, varies with the preparation used. With the Talbotype iodized paper, the greatest blackening is found on the extreme limit of the violet ray. When bromide of silver is the sensitive material, the chemical action is prolonged towards the red rays. When chloride of gold is used, the maximum is found between the green and the blue rays, and the chemical action does not extend beyond the violet more than half as far as when the salts of silver are used. In Figure 146, 1 represents the space occupied by the

Fig. 146.



luminous spectrum on white paper; 2, the chemical spectrum on bromide of silver; 3, the Talbotype spectrum.

Inactive spaces occur in the chemical spectrum, which, as Becquerel and Draper have shown, correspond exactly with the dark lines found in the visible spectrum; but they extend also into the prolongation beyond the violet, and occur there in great numbers. These fixed lines may be obtained upon Talbotype paper, or, better still, upon a surface of collodion.

SUMMARY.

Light either causes certain chemical compounds to decompose or gives them a disposition to do so. (172.)

Hence light can be made to fasten upon properly prepared surfaces the images which fall upon them in the camera. (173.)

The daguerreotype process was discovered by Daguerre, in 1839; photographic printing, by Talbot, in the same year; the collodion process, by Archer, in 1851. (173 – 175.)

The most refrangible rays of the spectrum have the most powerful chemical action.

The chemical spectrum extends beyond the luminous spectrum at the violet end, and has blank spaces. These spaces correspond to Fraunhofer's lines, which are also chemically inactive. (176.)

CONCLUSION.

A luminous body sends out light in every direction, which diminishes in intensity as the square of the distance increases. These rays of light traverse space in straight lines, and with a velocity of about 190,000 miles a second.

When rays of light meet a different medium from that through which they have been passing, they are partially reflected and partially transmitted. The reflected portion is either diffused or else reflected regularly. In the latter case the angle of reflection always equals the angle of incidence. The transmitted portion is refracted towards or from a perpendicular to the surface, according as the new medium is more or less dense than the old one.

In passing through a prism a ray of light is twice refracted in the same direction, and also dispersed into a colored band, called the *spectrum*, which differs in length with the material of the prism. This dispersion shows that a ray of white light is really a bundle of rays of different colors and of different refrangibility. The rays of white light are continually sifted as they fall upon bodies, each body absorbing some particular color or colors, and transmitting or dispersing the others. It is this which gives bodies their color.

Incandescent solids give out rays of all the prismatic colors, but incandescent gases give out rays of only particular colors. By means of the spectroscope we can analyze the light emitted by an incandescent gas, and find out the elements of which it is composed. A gas absorbs the same rays that it emits when incandescent.

When examined with the spectroscope, solar and stellar light give spectra crossed by dark lines. Such spectra show that the light comes from a solid or liquid nucleus, surrounded by a gaseous envelope, and enable us to find what elements exist in these envelopes.

Rays of light interfere in such a way as to show that light is propagated by means of waves. These waves are exceedingly minute, and are longest in red, and shortest in violet light. Difference in color is then analogous to difference in pitch, the difference in both cases being caused by a difference in the rapidity of vibration. *Tint* in color is analogous to *quality* in sound, both being the result of the mixture of vibrations of different periods. While sound-waves are propagated chiefly in the air, light-waves are propagated in the ether. Light, like sound, originates in the vibrations of particles of gross matter; but the vibrations which originate light are much more minute and more rapid than those which give rise to sound. The molecules of a luminous body are usually capable of executing vibrations of several periods, and hence the light which they give out is seldom homogeneous. As in sound, so in light, a body is capable of intercepting or absorbing the vibrations whose periods are synchronous with those of its own molecules. Double refraction and polarization show that while in sound the vibrations are longitudinal, they are transverse in light, and that in ordinary white light these vibrations are executed in every plane. On passing through a crystalline body these vibrations are sorted and arranged in two sets. When the vibrations are all executed in the same plane the ray is said to be polarized. Two rays of polarized light cannot interfere so as to destroy each other unless they are polarized in the same plane; but they may interfere so as to make the molecules of the resultant ray move in circles or ellipses, or so as to twist the plane of polarization.

The rainbow is caused by the reflection and refraction of light in the rain-drop. The colors are due partially to dispersion and partially to interference.

An image of an object can be formed in the focus of a converging lens or of a concave mirror. The rays of light on entering the eye are brought to a focus upon the retina by means of the cornea and crystalline lens. The vibrations of the ether are taken up by the rods and cones, and communicated to the nerve-fibres, and thence to the brain. The distinctness of vision increases with the distinctness, the size, and the brightness of the image upon the retina; provided the illumination is not too strong, in which case the eye is blinded. Perfect eyes can adjust themselves to any distance from a few inches to infinity. Other eyes, owing to a defective form of the ball, can adjust themselves only to a limited range of distances, some being able to see with distinctness only near objects, and others only remote ones. These defects can be partially remedied by the use of glasses. As the eye grows old it loses its power of adjustment.

The size of the image upon the retina increases as the object is brought nearer to the eye. The microscope is an instrument which enables the eye to see an object at a very short distance; and the telescope, an instrument which enables it to see a very distant object.

The more refrangible rays of the spectrum have a chemical action, which is now employed in taking photographic pictures.

III.

HEAT.

NATURE AND PROPAGATION OF HEAT.

RADIATION.

177. *Heat is Radiated in all Directions.* — When we come near a stove we feel its heat, no matter on what side of it we may be; that is, the stove *radiates* its heat in all directions.

Again, if a small metallic sphere be heated, and delicate thermometers be placed on different sides of it at equal distances from its centre, they will all indicate the same temperature; showing that the sphere radiates heat equally well in every direction.

Radiant heat, like light, diminishes in intensity as the square of the distance increases, and for the same reason.

178. *Heat traverses Space in Straight Lines and with the Velocity of Light.* — Heat and light come to the earth together in the sun's rays, and we have seen that these move in straight lines and with a velocity of about 190,000 miles a second.

179. *Luminous and Obscure Heat.* — Heat which is radiated from a non-luminous source, as from a ball heated below redness, is called *obscure* heat; while that radiated from a luminous source, as from the sun or from a ball heated to redness, is called *luminous* heat.

180. *Diathermanous Bodies.* — Some substances, as air, allow radiant heat to pass readily through them, and are

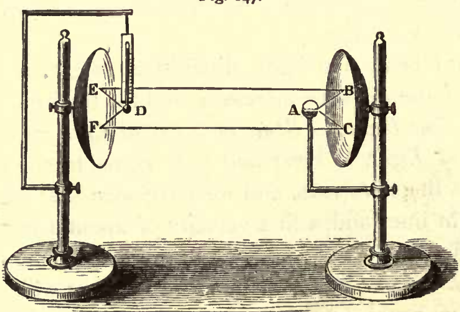
called *diathermanous*. The term is derived from the Greek words *dia*, *through*, and *thermos*, *heat*.

If a plate of glass be held up before an iron ball heated to dull redness, a delicate thermometer held behind the plate will be scarcely, if at all, affected. If, however, a plate of rock salt be put in place of the glass, the thermometer rapidly rises. Glass, then, though one of the most transparent bodies, is by no means one of the most diathermanous. Rock salt is the most diathermanous of all known solids, and is to radiant heat what glass is to light.

181. *Heat is Reflected in the Same Way as Light.* — That luminous heat is reflected in the same way as light is shown by the fact that, when the sun's rays are reflected to a focus by a concave mirror, that focus is the hottest, as well as the brightest, part of the beam.

At *A* (Figure 147) in the focus of the concave mirror *B C* is placed a copper ball heated below redness, and the

Fig. 147.

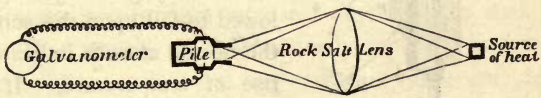


bulb of a delicate thermometer is placed at *D* in the focus of the concave mirror *E F*. The mercury rises at once. If the thermometer be moved away from *D* in any direction, the mercury falls. It is evident, then, that the heat-rays are concentrated at the focus of the mirror *E F*. Now we know that light-rays diverging from *A* would, on falling upon the mirror *B C*, be reflected in parallel lines to the mirror *E F*, and from this mirror to its focus *D*; and it is clear that the heat-rays have been reflected in the very same way.

Radiant heat, then, both luminous and obscure, is reflected in the same way as light.

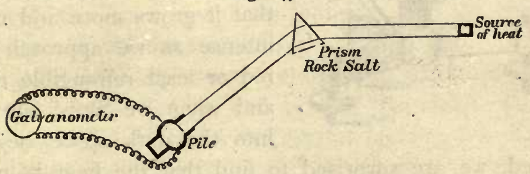
182. *Radiant Heat is Refracted in the Same Way as Light.* — That luminous heat is refracted like light is shown by the fact that the heat of the sun's rays is refracted by a converging lens to the same focus as the light. The refraction of ordinary obscure heat cannot be shown by a glass lens, since it is not sufficiently diathermanous (180). If, however, a lens of rock salt be held before a source of obscure heat, as shown in Figure 148, and the face of a thermopile * be placed at the focus of this lens,

Fig. 148.



the galvanometer needle at once turns aside, showing a rise of temperature. If the face of the pile be placed anywhere else than at the focus, no rise of temperature is indicated.

Fig. 149.



Again, if the rays of obscure heat be allowed to fall upon a prism of rock salt, they will be turned aside, as shown in

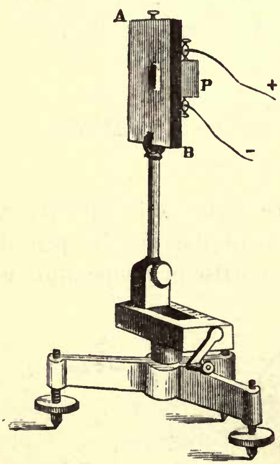
* For the thermo-electric battery, or thermopile, see § 248, p. 248, and § 286, p. 284.

Figure 149, in exactly the same way as rays of light would be in passing through the same prism.

These experiments show that radiant heat, whether luminous or obscure, is refracted just like light.

183. *Heat is Dispersed in the Same Way as Light.* — In Figure 150 we have a thermopile of peculiar construction. In the middle of the brass plate *A B* is a narrow vertical slit, so arranged that its width can be varied at pleasure. Behind this slit is the face of the thermopile, whose elements are arranged not in a cube, as usual, but in a single row. By means of the ivory handle seen at the bottom, the brass plate which serves as a screen can be moved to and fro with great regularity and precision. If now this thermopile be connected with a delicate galvanometer, and the solar spectrum from an ordinary glass lens be allowed to fall upon the screen, the needle at once indicates a rise of temperature. If we move the face of the pile backward and forward, we find that the heat is dispersed throughout the whole length of the spectrum, but that it grows more and more intense as we approach the red or least refrangible end; and when we move the slit into the dark space beyond the red, we are surprised to find that the heat is more intense there than anywhere else. The heat, however, extends but a little way beyond the red end.

Fig. 150.



This experiment shows, (1) that radiant heat is dispersed like light in passing through a prism; (2) that obscure as well as luminous heat is radiated from a luminous source; and (3) that obscure heat is less refrangible than luminous heat.

184. *Heat and Light are one and the same.* — We have now seen that radiant heat and light are reflected, refracted, and dispersed in precisely the same way. It has also been found by difficult and delicate experiments that radiant heat can also be *polarized* in the same way as light. These facts seem to lead to the conclusion that light and heat are the same thing, and the following fact proves this beyond a doubt.

We have learned that the solar spectrum is crossed by dark lines, known as *Fraunhofer's lines* (112). Now an examination of the spectrum with a very delicate thermopile has shown that these dark lines are also devoid of heat, and, furthermore, that similar dark or *cold* lines exist in the obscure part of the spectrum beyond the red end, where the heat is most intense. Again, these dark lines have been shown to be chemically inactive, and similar inactive lines are found beyond the violet end in the obscure *chemical* part of the spectrum. The existence of these blank lines throughout the whole length of the spectrum, in the obscure as well as in the luminous part, and the absence of both heat and chemical activity in the dark lines found in the luminous part, prove conclusively that the thermal, the luminous, and the chemical rays are one and the same thing.

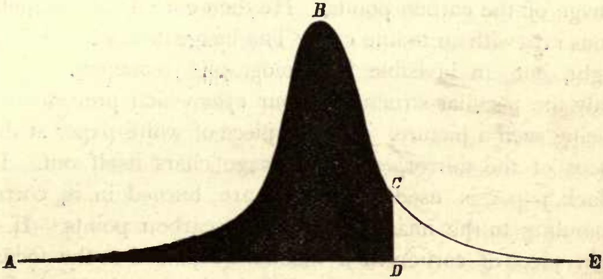
Passing from the obscure end of the spectrum beyond the red to the obscure end beyond the violet, we meet with vibrations of greater and greater rapidity, but differing in nothing else. A portion of these vibrations at the lower or *thermal* end of the spectrum are able to affect only those nerves which give us the sensation of heat; another portion, including the luminous part of the spectrum, are able to affect these nerves and at the same time the nerves of the eye, and also to develop chemical action; a third portion, or those beyond the violet end, are able only to cause chemical action. Luminous heat and light, then, are exactly the same thing; and obscure heat differs from luminous heat only as one color of the spectrum differs from another.

If there is need of further proof that obscure heat differs from light only in the rapidity of the vibration, it is furnished by an experiment of Dr. Draper's. He gradually raised the temperature of a platinum wire till it was of a white heat, and examined its spectrum throughout the process. At first the spectrum contained only the obscure thermal rays; then the least refrangible red rays appeared, followed in succession by the orange, yellow, green, blue, indigo, and violet; and after these came the obscure chemical rays.

185. *The Proportion of Obscure and Luminous Radiation in the Electric Light and in Sunlight.* — Professor Tyndall discovered that a solution of iodine in bisulphide of carbon, which is so opaque that a layer of .07 of an inch in thickness is sufficient to cut off all the light from the most brilliant gas-flame, is almost perfectly diathermanous to obscure heat, even in very much thicker layers. A solution of this kind, contained in a narrow cell whose sides are polished plates of rock salt, separates sharply the obscure from the luminous heat, whatever may be their source. With this delicate apparatus he examined the obscure heat in the rays of the sun and in the electric light, and found that it was far greater than the luminous heat. By giving the cell the form of a prism, he obtained a spectrum of this obscure heat. Figure 151 shows the proportion of the obscure thermal to the luminous part of the spectrum of the electric light. The height of the curve shows the intensity of the radiation at each point. It is seen that the luminous rays of the electric light are

insignificant in comparison with the obscure ones. This same thing is true of the radiations from the sun, though the disproportion between the luminous and the obscure

Fig. 151.



parts is not quite so great, owing probably to the fact that many of the obscure rays are absorbed in passing through the atmosphere.

186. *The Obscure Radiation increases in Intensity with the Temperature.* — Tyndall heated a spiral of platinum wire from dull redness to full white heat, and by means of the iodine solution examined its obscure radiations. He found that as its temperature rose it not only gave off more and more refrangible rays, as Draper had shown (184), but also that its obscure radiations were powerfully augmented. It had previously been supposed that the effect of raising the temperature of a body was only to add to its radiations those of shorter periods. Tyndall's experiment, however, has shown that the effect of raising the temperature is both to add quicker vibrations and to augment the intensity of those which already exist.

The hotter a body, then, the more powerful its obscure radiations.

187. *Invisible Foci.* — By means of the opaque iodine solution, Tyndall was able to show effects of obscure heat far more striking than had ever been shown before, for he could use the obscure radiations from the most intense

sources of heat. He placed a concave mirror behind the carbon points in the electric lamp, and converged its powerful beam to a focus a short distance in front. In this focus there was, of course, formed a very bright luminous image of the carbon points. He then cut off all the luminous rays with an iodine cell. The image disappeared from sight, but an invisible "thermograph" remained. It is only the peculiar structure of our eyes which prevents our seeing such a picture. Place a piece of white paper at the focus of the mirror, and the image chars itself out. If black paper is used, two holes are burned in it, corresponding to the images of the two carbon points. If a thin piece of carbon in a vacuum be placed at the focus, the radiant heat is converted into light, and the latent image becomes visible. A thin sheet of platinized platinum will bring out the image even in the air. The intense heat at this invisible focus may be shown by many other experiments, as the melting of lead, the burning of zinc and magnesium, and the like.

Similar experiments may be tried by bringing the luminous rays to a focus by a rock-salt lens, and interposing an iodine cell, or, what is better, a hollow lens of rock salt filled with the iodine. Sunlight produces similar effects, and in using it a glass lens may be substituted for a rock-salt one, though with less brilliant results.

188. *Calorescence and Fluorescence.* — In the above experiment of Tyndall's, the platinum foil cannot have become hotter than the focus itself, yet it became luminous while the focus was obscure. Again, when a cylinder of lime is put in the oxy-hydrogen flame, its temperature cannot be higher than that of the flame, yet it becomes intensely luminous. Platinum, then, and other solids have the power of raising the refrangibility of the obscure rays so as to render them luminous. This change of refrangibility is called *calorescence.*

On looking through a prism at the incandescent image of the carbon points on the platinum foil, Tyndall found that the light from it gave a complete spectrum, showing that the obscure rays had been converted by the platinum into red, orange, yellow, green, blue, and even violet.

When the ordinary spectrum is allowed to fall on a screen washed over with a solution of the sulphate of quinine, the ultra-violet rays become luminous, showing that their refrangibility has been lowered. This phenomenon, which is just the opposite of calorescence, is called *fluorescence.*

Phosphorescence, that is, the property which certain bodies have of shining in the dark after they have been exposed to the light, is probably nothing but a persistent form of fluorescence.

SUMMARY.

Heat is radiated from its source in all directions. (177.)

It traverses space in straight lines with the velocity of light. (178.)

Radiated heat may be luminous or obscure. (179.)

Bodies which allow heat to pass readily through them are called *diathermanous.* (180.)

Radiant heat is reflected, refracted, and dispersed in the same way as light.

Obscure heat is less refrangible than luminous heat. (181 – 183.)

Heat and light are the same thing.

The different kinds of heat differ only in the rapidity of the vibrations in which they originate and are propagated. (184.)

The obscure radiations of the electric lamp and the sun are much more abundant than the luminous radiations. (185.)

The obscure radiations increase in intensity as the temperature of the body rises. (186.)

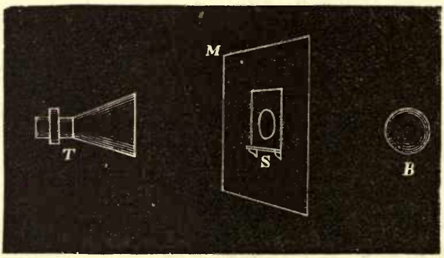
Invisible foci may be formed by obscure radiations. (187.)

The refrangibility of the obscure thermal radiations may be raised so that they will become luminous; while that of the obscure chemical radiations may be lowered. The former change of refrangibility is called *calorescence;* the latter, *fluorescence.* (188.)

ABSORPTION.

189. *Different Solids and Liquids absorb the Same Kind of Heat with Different Degrees of Readiness.* — In Figure 152 *M* is a perforated screen, *B* is a copper ball heated to dull redness, and *T* is a thermopile. A plate of glass is put upon the shelf at *S* behind the screen. Few rays

Fig. 152.



of heat reach the pile. If a plate of rock salt of the same thickness be substituted for the glass, abundance of heat reaches the pile. The diathermancy of liquids can be found in the same way, by enclosing them in a glass, or, better, a rock-salt cell, which is placed upon the shelf. It is found in this way that different solids and liquids absorb the same kind of heat very differently.

190. *The Same Solid or Liquid absorbs Heat of Different Kinds in Different Proportions.* — By using different sources of heat, such as a Locatelli lamp, copper of different temperatures, and incandescent platinum, it is found that the same solid or liquid absorbs heat from these sources in very different proportions.

In this way Melloni constructed the following Table, in which the heat from each source transmitted by each substance is compared with that from the same source transmitted by the air, the latter being called 100 : —

Names of substances reduced to a common thickness of .1 of an inch (2.6 millim.).	Transmissions : percentage of the total radiation.			
	Locatelli Lamp.	Incandescent Platinum.	Copper at 400° C.	Copper at 100° C.
1 Rock salt	92.3	92.3	92.3	92.3
2 Sicilian sulphur	74.0	77.0	60.0	54.0
3 Fluor spar	72.0	69.0	42.0	33.0
4 Beryl	54.0	23.0	13 0	0.0
5 Iceland spar	39.0	28.0	6.0	0.0
6 Glass	39.0	24.0	6.0	0.0
7 Rock crystal (clear)	38.0	28.0	6.0	3.0
8 Smoky quartz	37.0	28.0	6.0	3.0
9 Chromate of potash	34.0	28.0	15.0	0.0
10 White topaz	33.0	24.0	4.0	0.0
11 Carbonate of lead	32.0	23.0	4.0	0.0
12 Sulphate of baryta	24.0	18.0	3.0	0.0
13 Felspar	23.0	19.0	6.0	0.0
14 Amethyst (violet)	21.0	9.0	2.0	0.0
15 Artificial amber	21.0	5.0	0.0	0.0
16 Borate of soda	18.0	12.0	8.0	0.0
17 Tourmaline (deep green)	18.0	16.0	3.0	0.0
18 Common gum	18.0	3.0	0.0	0.0
19 Selenite	14.0	5.0	0.0	0.0
20 Citric acid	11.0	2.0	0.0	0.0
21 Tartrate of potash	11.0	3.0	0.0	0.0
22 Natural amber	11.0	5.0	0.0	0.0
23 Alum	9.0	2.0	0.0	0.0
24 Sugar candy	8.0	1.0	0.0	0.0
25 Ice	6.0	0.5	0.0	0.0

The following Table gives the per cent of total radiation transmitted by different liquids : —

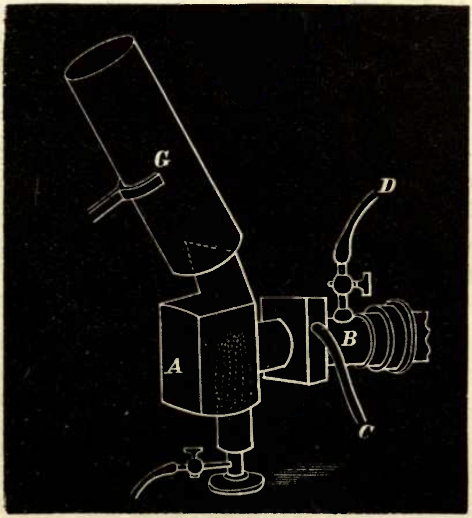
Names of Liquids.	Percentage of total radiation transmitted.
Bisulphide of carbon	63
Bichloride of sulphur	63
Protochloride of phosphorus	62
Essence of turpentine	31
Olive oil	30
Naphtha	28
Essence of lavender	26
Sulphuric ether	21
Sulphuric acid	17
Hydrate of ammonia	15
Nitric acid	15
Absolute alcohol	15
Hydrate of potash	13
Acetic acid	12
Pyroligneous acid	12
Concentrated solution of sugar	12
Solution of rock salt	12
White of egg	11
Distilled water	11

191. *Quality of Heat.* — If the rays which have passed through a plate of any substance be allowed to fall upon a second plate of the same, they are transmitted in much larger proportion than at first. The rays which fall upon the first plate are sifted, and those which cannot pass through that substance are absorbed. When, therefore, the rays fall upon the second plate, they are nearly all transmitted.

From the fact that the heat radiated from different sources is absorbed differently by the same substance, it is said to be of different *quality*. In no case is the heat homogeneous, and in the heat radiated from different sources vibrations of different periods are differently mixed. It is these different mixtures of vibrations of different periods that give to the heat from each source its peculiar quality; as the mixture of rays of different periods gives to the light from different bodies its peculiar tint.

192. *Different Gases absorb the Same Quality of Heat in Different Proportions.* — In Figure 153, *A* is a copper box, against one face of which a steady gas-flame is made to play. *G* is a chimney, and *B* is an air-chamber, beyond which is a long glass tube, both ends of which are closed with rock-salt plates. The pipe *D* connects this chamber with an air-pump. The chamber is surrounded with a collar through which water is kept flowing, in order that

Fig. 153.



the walls may not become heated. The heat radiated from the copper box passes first through this chamber and then through the tube beyond. The tube is first filled with carefully dried air, and the deflection of the galvanometer needle is noted. The tube is next filled with carefully dried olefiant gas; and it is found that only about .001 as much heat is radiated through the tube as at first. This shows that different gases absorb the same quality of heat very differently.

The following table is taken from Tyndall : —

Name of Gas.	Absorption under a pressure of one atmosphere.
Air	1
Oxygen	1
Nitrogen	1
Hydrogen	1
Chlorine	39
Hydrochloric acid	62
Carbonic oxide	90
Carbonic acid	90
Nitrous oxide	355
Sulphide of hydrogen	390
Marsh gas	403
Sulphurous acid	710
Olefiant gas	970
Ammonia	1195

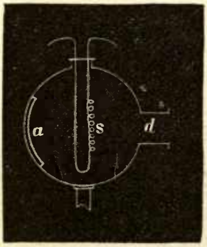
If, instead of comparing the gases at the common pressure of one atmosphere, or 30 inches, we compare them at the common pressure of one inch, we shall find their absorptive power differing in even a more striking manner, as is shown in the following table from Tyndall : —

Name of Gas.	Absorption under 1 inch pressure.
Air	1
Oxygen	1
Nitrogen	1
Hydrogen	1
Chlorine	60
Bromine	160
Carbonic oxide	750
Hydrobromic acid	1005
Nitric oxide	1590
Nitrous oxide	1860
Sulphide of hydrogen	2100
Ammonia	7260
Olefiant gas	7950
Sulphurous acid	8800

"What extraordinary differences," Tyndall adds, "in the constitution and character of the ultimate particles of various gases do the above results reveal! For every individual ray struck down by the air, oxygen, hydrogen, or nitrogen, the ammonia strikes down a brigade of 7,260 rays; the olefiant gas, a brigade of 7,950; while the sulphurous acid destroys 8,800."

193. *The Same Gas absorbs Different Qualities of Heat in Different Proportions.* — In Figure 154 we have what is called a *platinum lamp*. *s* is a spiral of platinum wire within a glass globe; *d* is an opening in the side of the globe through which the heat from the spiral is radiated; *a* is a concave mirror for collecting and condensing the heat. The platinum spiral is connected with a galvanic battery, and by regulating the strength of the current we can heat the wire to any desired temperature. By using this lamp as a source of heat, Tyndall showed that the same gas or vapor absorbs different qualities of heat very differently. Some of the results of his experiments are given in the following Table: —

Fig. 154.



Name of Vapor.	Source of heat: platinum spiral.			
	Barely visible.	Bright-red.	White-hot.	Near fusion.
Bisulphide of carbon	6.5	4.7	2.9	2.5
Chloroform..................	9.1	6.3	5.6	3.9
Iodide of methyl............	12.5	9.6	7.8	...
" " ethyl..............	21.3	17.7	12.8	...
Benzole.....................	26.4	20.6	16.5	...
Amylene.....................	35.8	27.5	22.7	...
Sulphuric ether	43.4	31.4	25.9	23.7
Formic "	46.2	31.9	25.1	21.3
Acetic "	49.6	34.6	27.2	....

The gradual increase of penetrative power as the temperature rises is here very manifest. By raising the temperature of the spiral from a barely visible to an intensely white heat, we reduce the absorption in the case of bisulphide of carbon and chloroform to less than one half.

194. *Vapors absorb the Same Quality of Heat in the Same Order as their Liquids.* — Tyndall has arranged the following liquids and their vapors in the order in which he found them to absorb the same quality of heat, the quantity of vapor used in each case being proportional to that of the liquid : —

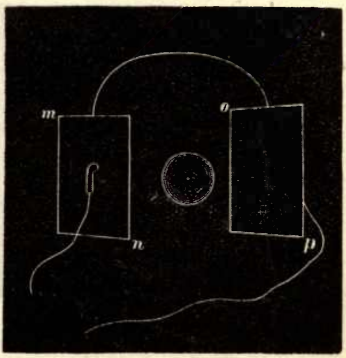
Liquids.	*Vapors.*
Bisulphide of carbon,	Bisulphide of carbon,
Chloroform,	Chloroform,
Iodide of methyl,	Iodide of methyl,
" " ethyl,	" " ethyl,
Amylene,	Amylene,
Sulphuric ether,	Sulphuric ether,
Acetic, "	Acetic "
Formic, "	Formic "
Alcohol,	Alcohol,
Water,	Water.*

We see from this table that the order of absorption in vapors and their liquids is the same. When the molecules are freed from the bonds which hold them in the liquid state, they do not change their absorptive power.

195. *Good Absorbers are Good Radiators.* — Coat all the sides of a tin box except one with a varnish or lamp-black, fill it with boiling water, and expose each side in turn to the face of a thermopile. It will be found that the heat is radiated slowly from the metallic surface as compared with the coated surfaces.

* Aqueous vapor, when unmixed with air, condenses so readily that it cannot be directly examined in the experimental tube.

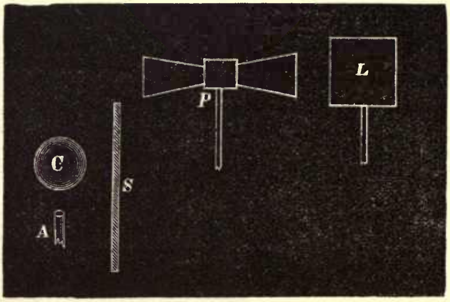
Fig. 155.



In Figure 155 we have a plate of tin *m n* uncoated, and another *o p* coated with lamp-black. The plates are connected by a wire at the top, and to the back of each is soldered a little bar of bismuth. These bars are connected with a delicate galvanometer. If we heat the junction of one of these bars with the plate by putting the finger upon it, the galvanometer shows that the current is flowing in one direction ; if we allow this to cool and heat the other in the same way, the galvanometer shows a current flowing in the opposite direction ; if we heat them both equally at the same time, no current is indicated. A heated copper ball is now placed just half-way between the two plates, so as to radiate heat equally to each. The needle at once shows a current flowing from the plate *op*, which must therefore have become more heated than *m n*. The coated plate, which was the best radiator, is, therefore, the best absorber.

In Figure 156 *P* is a thermopile connected with a galvanometer ; *C*, a heated copper ball placed above a tube *A*. The direct radiation of the ball is cut off from the pile by means of the screen *S*. *L* is a cube filled with hot water and placed at such a distance from the pile as to warm the face towards it just as much as the opposite face is warmed by the current of air streaming up over the hot ball. Different gases are now forced through the tube against the ball, by which they are heated. On rising above the screen, they radiate their heat to the pile. If they radiate just as much heat as the air, the needle will

Fig. 156.



not move; if they radiate more heat than the air, it will move in such a way as to show that the left face of the pile is heated more than the other; if less than the air, it will move in the opposite direction. By noticing how much the needle turns in each case, we can compare the radiating power of the different gases used. In this way it is found that those gases which are the best absorbers are also the best radiators.

196. *The Molecules of a Substance radiate Heat by Communicating their Motion to the Ether, and absorb Heat by Taking up Motion from the Ether.* — In the study of light we have learned that the molecules of substances are immersed in the all-pervading ether, and that the molecules of each substance are capable of vibrating in certain definite periods. When the ethereal vibrations dash against the molecules of a body, these molecules will take up the vibrations which are synchronous with their own, and allow the others to pass on. The former vibrations are said to be *absorbed*, the latter *transmitted*. *Diathermancy*, then, is synonymous with *discord;* and *adiathermancy* (the opposite of diathermancy) with *concord.* Hence arises the power of bodies to sift the vibrations which fall upon them. The molecules select and absorb the vibrations

which are synchronous with their own, and allow the others to pass.

When, on the other hand, bodies radiate heat, they impart some of their motion to the ether which surrounds them. Bodies can radiate only those vibrations which their own molecules can perform. Hence different bodies radiate different qualities of heat. That bodies radiate the same kind of heat as that which they absorb is shown by the fact that they are nearly opaque to their own radiations. Even rock salt, which is so diathermanous, is nearly opaque to the vibrations given out by heated salt.

197. *The Absorptive Power of a Body depends upon its Molecular Constitution.* — An examination of the preceding tables will show that elementary bodies, such as the metals, oxygen, and nitrogen, are poor absorbers, while compound bodies, such as olefiant gas, sulphurous acid, and ammonia, are good ones. This is as we should expect, since the more complex a molecule becomes by the combination of different atoms, the more likely it will be to intercept the vibrations of the ether in which it is immersed. The great absorptive power of lamp-black, one of the forms of carbon, would seem to be at variance with this view. Lamp-black, however, is not pure charcoal, but contains various compounds of carbon and hydrogen ; while charcoal itself is an allotropic state of carbon. And the most probable explanation of allotropic states is that the atoms are differently grouped into molecules. While oxygen is almost perfectly transparent to heat, ozone, an allotropic state of oxygen, is quite a good absorber. This is probably due to the fact that in the charcoal and ozone the atoms are grouped in such a way as to form complex molecules.

The power of bodies to absorb vibrations from the ether is likely to throw much light on their molecular constitution.

198. *The Molecules of all Bodies are in Motion.* — It would seem, then, that all the molecules of gross matter are in constant vibration; and that, when acted upon by heat or other force, these molecules are made to perform their fundamental vibrations with greater energy, and to add to these higher and higher harmonics. Our organs of sense are instruments for intercepting these vibrations and transmitting them to the brain, where they tell us all that we know of the external world. The eye seems to have been especially formed to give us a glimpse of the *beauty* of these vibrations.

SUMMARY.

Different qualities of heat result from different mixtures of vibrations of different periods. (191.)

The same solid, liquid, or gas absorbs different qualities of heat in different proportions; while different solids, liquids, or gases absorb the same quality of heat in different proportions. (189 – 193.)

Vapors absorb the same qualities of heat in the same order as their liquids. Water is the best absorber among liquids, and watery vapor among gases. (194.)

Good absorbers are good radiators. (195.)

The molecules of a substance radiate heat by communicating their vibrations to the ether, and absorb heat by taking up vibrations from the ether. (196.)

The absorptive power of a body depends on its molecular constitution. (197.)

The molecules of all bodies seem to be in vibration; and when they are heated their original vibrations are rendered more intense, and more rapid vibrations are added. (198.)

EFFECTS OF HEAT ON BODIES.

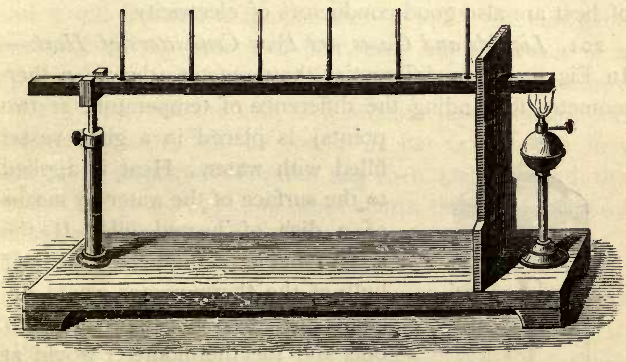
CONDUCTION.

199. *The Molecules of a Body communicate their Vibrations to one another.* — We have now seen that on absorbing heat the molecules of a body are made to vibrate with greater energy and in quicker periods. When one end of a poker is placed in the fire, it soon becomes red hot, and the heat slowly travels from this end to the other. This heat cannot have been radiated, since radiant heat travels at the rate of 190,000 miles a second. The molecules of a solid are then able to communicate their vibrations to one another as well as to the ether.

This transmission of heat from molecule to molecule of gross matter is called *conduction.*

200. *Different Solids conduct Heat differently.* — If several thermometer bulbs be inserted in a metallic rod, as shown

Fig. 157.



in Figure 157, and one end of the bar be heated, the mercury will begin to rise in the thermometer nearest the heated end, and then in the others successively; but no amount of heating will make the mercury rise as high in the last thermometer as in the first. If now rods of other metals of the same length and thickness are tried in the same way, it will be found that the difference of temperature at the ends of the rods is not always the same. The less the difference of temperature, the better the body conducts heat.

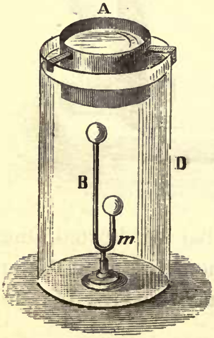
The following Table of conductivity is from Tyndall : —

Name of Substance.	Conductivity.	
	For Electricity.	For Heat.
Silver..........	100	100
Copper........	73	74
Gold..........	59	53
Brass.........	22	24
Tin............	23	15
Iron...........	13	12
Lead..........	11	9
Platinum......	10	8
German silver.	6	6
Bismuth.......	2	2

It will be seen that the metals differ widely in conductive power, and that those which are good conductors of heat are also good conductors of electricity.

201. *Liquids and Gases are Poor Conductors of Heat.* — In Figure 158 a differential thermometer (that is, a thermometer for finding the difference of temperature at two points) is placed in a glass vessel filled with water. Heat is applied to the surface of the water by means of a dish of heated oil. If the water conducted the heat, the upper bulb of the thermometer would become heated sooner than the lower one, and the thermometer would at once indicate a difference of temperature between the two bulbs. But the thermometer is scarcely affected.

Fig. 158.



This experiment shows that water is a poor conductor of heat. The same is true of other liquids, and even more so of gases.

SUMMARY.

The molecules of a heated solid communicate their vibrations to one another as well as to the ether. Heat thus communicated is said to be *conducted*. (199.)

Some solids conduct heat better than others. (200.)

Liquids and gases are poor conductors. (201.)

TEMPERATURE.

202. *Heat raises the Temperature of a Body.*— The most obvious effect of the heat absorbed by a body is a rise of temperature. This rise of temperature is indicated by the sense of touch, but more accurately by a thermometer.

203. *A Body in cooling* 1° *gives out just as much Heat as it takes to heat it* 1°. — Boil a quarter of a pound of water in a beaker, and plunge the bulb of a thermometer into it, and it will indicate a temperature of 212°. Remove the beaker from the source of heat, and add a quarter of a pound of water of a temperature of 70°. Stir the mixture a short time with the bulb of a delicate thermometer, and the temperature will be found to be 141°. The first quarter of a pound of water has then lost 71° and the second has gained 71°; in other words, the first in cooling 1° has given out just heat enough to warm the second 1°. The same is true of all other bodies.

204. *It requires Different Amounts of Heat to raise the Temperature of the Same Weight of Different Bodies* 1°. — If a piece of tin be heated to 212° by plunging it into boiling water, and it then be plunged into its own weight of water at 70°, the resulting temperature will be considerably below 141°; showing that tin in cooling 1° does not give

out heat enough to raise the water 1°. But the tin in cooling 1° gives out just as much heat as it takes to raise its temperature 1°. Hence it takes more heat to raise the temperature of a pound of water 1° than to raise that of a pound of tin 1°. If copper be used instead of tin, the resulting temperature will be higher, but still below 141°. It requires, then, less heat to raise the temperature of a pound of copper 1° than to raise that of a pound of water 1°, but more than it takes to raise that of a pound of tin 1°.

In this way it is found that it takes very different amounts of heat to raise the temperature of the same weight of different substances 1°.

205. *Unit of Heat.* — The thermometer indicates the rise of temperature in a body, but tells us nothing of the amount of heat required to raise the temperature. It is therefore desirable to have some unit by which the heat received by a body may be expressed. The unit usually taken is the amount of heat required to raise the temperature of a pound of water 1°. A unit of heat, then, is *the amount of heat required to raise the temperature of one pound of water* 1°.

206. *Specific Heat.* — The amount of heat required to raise the temperature of a pound of any substance 1°, expressed in units, is called the *specific heat* of that substance. Thus it requires $\frac{1}{30}$ of a unit of heat to raise the temperature of one pound of mercury 1° ; and the specific heat of mercury is therefore $\frac{1}{30}$ or .033.

When we know the specific heat of a body and also its weight, we can readily find how many units of heat it will take to raise its temperature any number of degrees. For instance, 10 pounds of iron have been raised 100° in temperature, and the specific heat of iron is .1138. To raise 10 pounds of iron 1° in temperature would, then, require 1.138 units of heat. To raise it 100°, would require 113.8 units of heat.

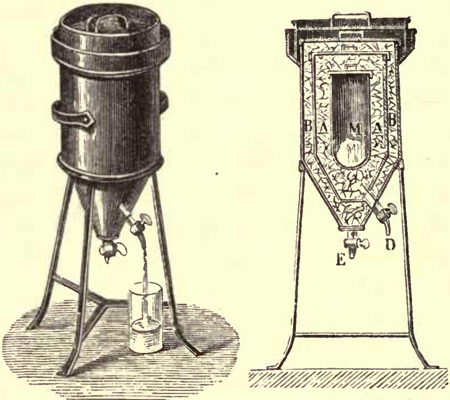
207. *The Method of finding Specific Heat by Mixture.* — One of the readiest ways of finding the specific heat of a body is by the *method of mixture*, as it is called. The substance is first weighed, then heated to a certain temperature, and plunged into a vessel of water, and the resulting temperature is noted. The weight of water and its temperature at the beginning of the experiment are supposed to be known. We then can find the number of units of heat which the water has received, and which of course have been lost by the heated substance. We also know the number of degrees the substance has cooled, and can therefore find how many units of heat one pound of it would give out in cooling 1°. Now this is the amount of heat which it would take to raise the temperature of one pound of it 1°, or its specific heat.

This method is simple, and would be satisfactory, were not the water losing heat by radiation during the experiment. We can, by trial, find very nearly the rate at which the water is radiating its heat, and thus calculate the loss.

208. *The Method of finding Specific Heat by Melting.* — Another method of finding specific heat is by melting ice. The substance is first weighed, then heated to a certain temperature, as 100°, and placed in the vessel *M* (Figure 159). This vessel is placed within the vessel *A*, the space between the two being filled with ice. The vessel *A* is placed in another, *B*, from which it is also separated by ice. Since the vessel *A* is surrounded by ice, the heat which melts the ice within it must come wholly from the vessel *M*. As the ice in *A* melts, the water runs off through the pipe *D*. It is necessary to know how much ice will be melted by one pound of water cooling 1°, or by one unit of heat. We need, then, only know how much ice is melted by any substance within the box *M*, in order to find how many units of heat it has given up. Dividing this by the weight of the substance

and by the number of degrees it has cooled, we get its specific heat.

Fig. 159.



Thus, suppose ten pounds of iron heated to 132° be placed in *M*, and allowed to cool 100°, and that it is found to give out 109 units of heat. 109 ÷ 10 = 10.9, which is the number of units of heat which would be given out by one pound cooling 100°; and 10.9 ÷ 100 = .109, which is the number of units one pound would give out in cooling 1°, or the specific heat of iron.

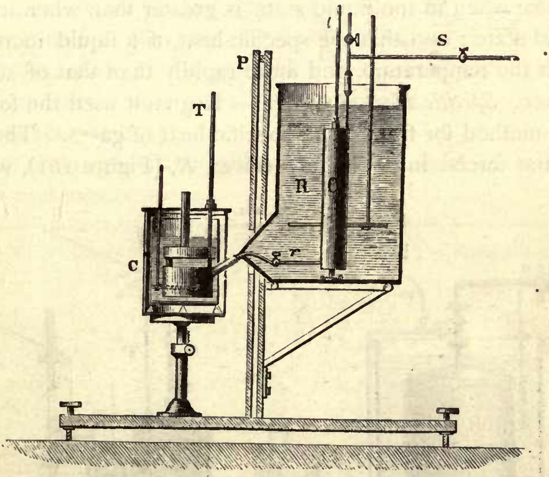
The specific heat of solids can be found by either of the above methods. The specific heat of a few substances is given in the following table:—

Substance.	Mean Specific Heat.	
	Between 32° and 212°.	Between 32° and 572°.
Iron	0.1098	0.1218
Mercury	0.0330	0.0350
Zinc	0.0927	0.1015
Antimony	0.0507	0.0549
Silver	0.0557	0.0611
Copper	0.0949	0.1013
Platinum	0.0355	0.0355
Glass	0.1770	0.1990

It will be seen from this table that the specific heat of a solid increases with the temperature. It will be noticed that the specific heat of solids is low compared with that of water, which is of course 1.00.

209. *Specific Heat of Liquids.* — Regnault has found the specific heat of a number of liquids by the following method. The liquid to be tried is put in the vessel *O* (Figure 160), which is placed in a large vessel, *R*, filled

Fig. 160.

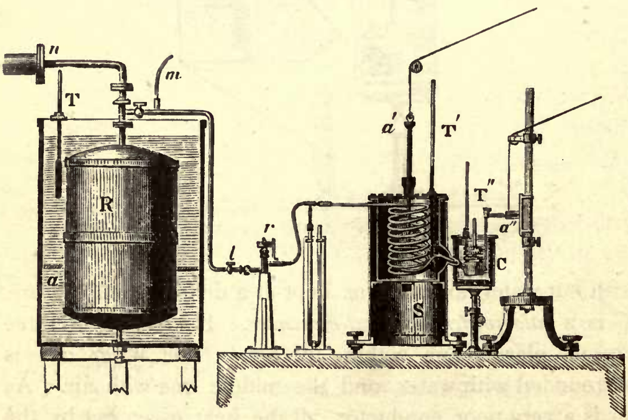


with hot water, and is thus kept at a definite temperature. *C* is a *calorimeter*, or *heat-measurer.* It consists of three vessels placed one within another. The inner one is surrounded with water, and the middle one with air. As air is a very poor conductor, all the heat given out by the inner vessel is kept in the water. The radiant heat of *R* is shut off from *C* by the screen *P*. When the cock *r* is opened, the liquid in the vessel *O* runs into the inner vessel of *C*, and there gives up its heat to the water in the middle vessel. The weight of the water in this vessel is supposed to be known, and its temperature at the beginning and end of the experiment is noted. We can then find how many units of heat the liquid in the inner vessel has given up to the water, and also how many degrees it has cooled. By finding the weight of the liquid in that vessel, we can find how many units of heat one pound of it would give out in cooling 1°, or its specific heat.

It is found in this way that the specific heat of a substance when in the liquid state is greater than when in the solid state; and that the specific heat of a liquid increases with the temperature, and more rapidly than that of solids.

210. *Specific Heat of Gases.* — Regnault used the following method for finding the specific heat of gases. The gas is first forced into a large receiver, *R*, (Figure 161), where

Fig. 161.



it is kept at a constant temperature by the water surrounding it. On opening the stopcock *l* the gas may, by an arrangement at *r*, be made to flow out through the pipe in a uniform stream. It is then passed through the coiled pipe in the chamber *S*, where it is heated to a high temperature, which is measured by the thermometer T'. It is then sent through the calorimeter C, where it gives up its heat to the water. By means of a manometer the pressure of the gas in R is found at the beginning and at the end of the experiment. The difference of pressure enables us to find the weight of gas which has passed through the calorimeter, for the density of a gas is inversely proportional to its pressure. If, for instance, the pressure of the gas at the end of the experiment is one half what it was at the beginning, its density will be only one half; and therefore one half of the gas must have passed out. When we know the weight of the gas which has passed through C, and the heat it has given up to the water, we can easily find its specific heat.

The following Table gives the specific heat of certain gases and vapors: —

Gas or Vapor.	Equal Vols.	Equal Weights.
Air	0.2375	......
Oxygen	0.2405	0.2175
Nitrogen	0.2368	0.2438
Hydrogen	0.2359	3.4090
Chlorine	0.2964	0.1210
Bromine	0.3040	0.0555
Nitrous oxide	0.3447	0.2262
Nitric oxide	0.2406	0.2317
Carbonic oxide	0.2370	0 2450
Carbonic acid	0.3307	0.2169
Bisulphide of carbon	0.4122	0.1569
Ammonia	0.2996	0.5084
Marsh gas	0.3277	0.5929
Olefiant gas	0.4160	0.4040
Water	0.2989	0.4805
Alcohol	0.7171	0.4534

211. *Influence of the State of a Substance on its Specific Heat.* — The same body has a higher specific heat in the liquid than in the solid state; while in the gaseous condition, again, its specific heat is less than when it is liquid. Thus, for instance, the specific heat of water is twice as

great as that of ice, and more than twice as great as that of steam.

The following Table exhibits the dependence of the specific heat on the physical state of the substance:—

Substance.	Specific Heat.		
	Solid.	Liquid.	Gaseous.
Water	0.5040	1.0000	0.4805
Bromine	0.0833	0.1060	0.0555
Tin	0.0562	0.0637	......
Iodine	0.0541	0.1082	......
Lead	0.0314	0.0402	......
Alcohol	......	0.5475	0.4534
Bisulphide of carbon	......	0.2352	0.1569
Ether	......	0.5290	0.4797

SUMMARY.

The heat which a body absorbs is partially used in raising its temperature. (202.)

A body in cooling 1° gives out just as much heat as it takes to warm it 1°. (203.)

It takes a different amount of heat to raise the temperature of the same weight of different substances 1°. (204.)

The amount of heat required to raise the temperature of one pound of water 1° is called a *unit of heat*. (205.)

The amount of heat required to raise the temperature of one pound of any substance 1°, expressed in thermal units, is called its *specific heat*. (206.)

The specific heat of a solid may be found by the method of *mixture* or by that of *fusion*. (207, 208.)

The specific heat of a liquid or of a gas may be found by means of the *calorimeter*. (209, 210.)

The same body has a higher specific heat in the liquid than in the solid state, but a lower specific heat when a gas than when a liquid. (211.)

CHANGE OF STATE.

212. *Heat causes Solids to melt.* — Place a dish of water at the temperature of 32° and a dish of ice at the same temperature side by side in a warm room, and hold a thermometer bulb in each. The temperature of the water will gradually rise, while that of the ice will not rise until the whole is melted. The heat, then, which has been absorbed by the ice has melted it, or changed its state.

The second effect of heat upon a body, then, is to change its state.

213. *The Melting-Point.* — Ice, as we have seen, has a temperature of 32°. Mercury melts at —38°; and alcohol at a temperature lower than we have yet been able to produce. On the other hand, phosphorus melts at 111°; iron at 2912°; and charcoal at a higher temperature than we have yet been able to produce. Though the melting-points of different substances vary so much, that of any one substance is, under the same circumstances, always the same.

The following Table of melting-points is from Stewart: —

Name of Substance.	Temperature of melting-point in degrees Fahrenheit.	Observer.
Mercury	—37.9	Stewart.
Oil of vitriol	—30.0	Regnault.
Bromine	+ 9.5	Pierre.
Ice	32.0	
Phosphorus	111.5	Schrötter.
Potassium	136.0	Regnault.
Sodium	207.7	"
Sulphur	239.0	Person.
Tin	451.0	"
Bismuth	512.0	"
Lead	620.0	"
Zinc	680.0	Pouillet.
Antimony	810.0	"
Silver (pure)	1832.0	"
Gold (pure)	2282.0	"
French wrought iron	2732.0	"
English wrought iron	2912.0	"

Certain bodies become soft or viscous before they melt. If a substance is capable of assuming a viscous or semi-solid state, we find that it does so before it begins to melt, and that it passes from a solid state through a semi-solid viscous state to that of a liquid of evident mobility. Sealing-wax is a very good example of a substance of this nature; when cold it is quite brittle, when heated it first grows plastic, and finally melts. In like manner, before fluidity iron becomes soft in such a manner that pieces may be easily welded together or moulded into any form; and this property of iron greatly enhances its value in the arts. Other instances might be mentioned, and a gradual passage from the solid to the liquid state characterizes a large number of bodies. Furthermore, certain substances, even after they have become unmistakably solid, acquire certain properties, such as hardness and brittleness, in greater perfection as the temperature continues to fall. Indeed, most hard bodies have high melting-points, and the diamond, which is the hardest, is not susceptible of fusion even at a very high temperature.

214. *Latent Heat of Liquids.* — If a pound of ice at 32° be mixed with a pound of water at 212°, the temperature, when the ice is melted, will be 50.5°. It has then taken 161.5 units of heat to melt a pound of ice and to raise its temperature from 32° to 50.5°, or 18.5°. It therefore takes 143 units of heat to melt a pound of ice. Heat always disappears in melting a solid; and this heat is called the *latent heat of fusion*, or the *latent heat of the liquid*, since it is *concealed* in the liquid.

By the latent heat of a liquid, then, we mean the number of units of heat required to melt one pound of the substance. Thus the latent heat of water is 143 units.

When the liquid passes back into the solid state again, its latent heat reappears as *sensible* heat.

215. *How to find the Latent Heat of Liquids.* — The readi-

est way of finding the latent heat of a liquid is to place the liquid at a known temperature in a calorimeter (209), allow it to solidify, and observe how much heat it gives out. This amount will be its latent heat *plus* the heat it loses in cooling down to its final temperature.

If, for instance, 32 pounds of melted lead at 630° be placed in a calorimeter and allowed to cool down to 200°, it will give out 439.664 units of heat. Now the specific heat of lead is .0314, and, multiplying this by 32, we get 1 unit of heat (nearly). The 32 pounds of lead, then, in cooling 1° give out 1 unit of heat; and in cooling 430°, as in the above experiment, 430 units. 439.664 — 430 = 9.664 units, which is the latent heat of lead.

The following Table, giving the latent heat of fusion of certain substances, is taken from Stewart: —

Substance.	Latent Heat of one pound.	
	Thermal Units.	Water = 1.
Water	79.250	1.000
Phosphorus	5.034	0.063
Sulphur	9.368	0.118
Nitrate of sodium	62.975	0.794
Nitrate of potassium	47.371	0.598
Tin	14.252	0.179
Bismuth	12.640	0.159
Lead	5.369	0.067
Zinc	28.130	0.355
Cadmium	13.660	0.172
Silver	21.070	0.266
Mercury	2.830	0.035

In this table the unit of heat is the amount of heat required to raise the temperature of one pound of water 1° *Centigrade*, which is $\frac{9}{5}$ of the English unit of heat based upon the *Fahrenheit* scale. The numbers in the first column can be changed to the English units by multiplying them by $\frac{9}{5}$.

216. *Heat causes Liquids to boil.* — Under the ordinary pressure, if water be raised to a temperature of 212°, it begins to boil, and its temperature then remains the same until it is all converted into steam. The heat, then, which the water absorbs changes it from the liquid to the gaseous state. Other liquids can be made to boil, but at very different temperatures. Any given liquid, under the same circumstances, always boils at the same temperature.

The following Table gives the boiling-points of several liquids: —

Name of Substance.	Boiling-Point Fahrenheit.	Observer.
Ether	94.8	Kopp.
Bisulphide of carbon	118.5	Pierre.
Formic ether	127.7	"
Bromine	145.4	"
Wood-spirit	149.9	Kopp.
Acetic ether	164.9	Pierre.
Alcohol	173.1	"
Benzole	176.8	Kopp.
Water	212.0	"
Formic acid	221.5	"
Acetic acid	243.1	"
Sulphuric acid	640.0	Marignac.
Mercury	662.0	Regnault.

217. *Latent Heat of Gases.* — If a thermometer be held in the steam just over boiling water, it will indicate a temperature of 212°. Now, as water is receiving heat all the time it is boiling, this heat must be latent in the steam. The latent heat of steam or of any other vapor is found by boiling the liquid, and sending the vapor through a calorimeter. The steam is reduced to a liquid, and cooled to a certain point. The amount of heat given out by the cooling of the liquid is readily calculated, and the surplus is the latent heat of the vapor.

In the following Table (from Stewart) the latent heat of several vapors is given: —

Substance.	Latent Heat of one pound.	
	In Thermal Units.	Steam = 1.
Water	535.90	1.000
Wood-spirit	263.70	0.492
Alcohol	202.40	0.378
Formic ether	105.30	0.196
Acetic ether	92.68	0.173
Ether	90.45	0.169
Bisulphide of carbon	86.67	0.162
Bromine	45.60	0.085
Perchloride of tin	30.53	0.057

The units in this table are the same as in the table in section 215.

218. *The State of a Body depends upon its Temperature.* — When a solid is heated, its temperature rises till it reaches the melting-point, where it remains stationary until the solid is melted. It then rises again until it reaches the boiling-point, where it again remains stationary until the liquid is converted into a gas. When a gas is sufficiently cooled, it goes through the same changes in the reverse order.

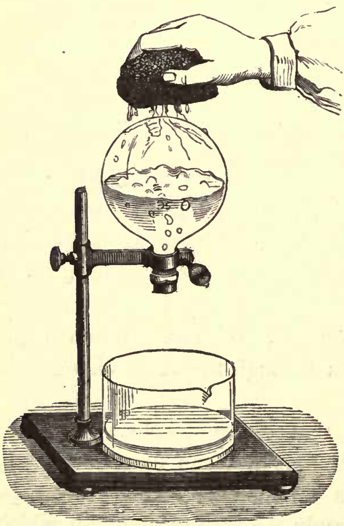
It is owing to the fact that different substances have very different boiling-points that they can exist in nature, some as solids, some as liquids, and some as gases. Hydrogen and oxygen are only the steam of liquids which boil at a very low temperature, perhaps four or five thousand degrees below zero.

219. *The Boiling-Point of Water falls as the Pressure on its Surface diminishes.* — Fill a flask two thirds full of water, boil it for some time, cork it tightly, removing it at the same time from the source of heat, and invert it, as shown in Figure 162. Pour cold water upon the flask, and it begins to boil again, and the boiling may be continued until the temperature of the water in the flask has fallen considerably below 212°.

At first the upper part of the flask is full of steam, whose elastic force causes it to press upon the water. When cold water is poured upon the flask, this steam is condensed, the pressure is diminished, and the water boils, though at a lower temperature.

The height of a mountain can be estimated with considerable accuracy by the difference between the boiling-points at its summit and at its base. Thermometers have been constructed on which are marked, not the degrees of temperature, but the number of feet of elevation. When the bulb of such a thermometer is plunged into boiling water, the mercury in the stem shows the elevation of the place.

Fig. 162.



It has already been shown that steam occupies very much more space than the same weight of water, and also that there is no cohesion among its molecules. When, therefore, water boils, both the cohesion of the liquid and the pressure of the atmosphere must be overcome, since both of these tend to keep the molecules together. Hence, when either the cohesive force or the external pressure is changed, the boiling-point will also change.

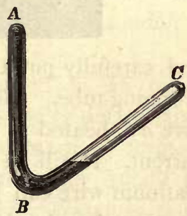
220. *The Boiling-Point of Water is raised by increasing the Cohesion of its Molecules.* — When any salt, as saltpetre, is dissolved in water, the boiling-point is raised. This is

probably owing to the fact that the presence of the salt causes the molecules to cohere more strongly.

Again, it is well known that water absorbs air and other gases; and the elastic force of these gases, which tends to separate the molecules, partially overcomes their cohesion. Hence we should expect that the cohesive force of water would be increased by removing the air from it.

The tube in Figure 163 is partially filled with water from which the air has been removed by long boiling. While the water is still boiling, the tube is sealed at *C*, so that there is no air in the tube. When the water is brought into the arm *A B* and made to come thoroughly in contact with the end *A*, the tube may be inverted, as shown in the figure, and the water will not flow out from this arm. The cohesive force among the molecules is now so great that they stick together, somewhat like those of a solid.

Fig. 163.



When the water is made to flow from one end of such a tube to the other, it strikes with a sharp metallic click, and not with the usual splashing sound. The latter is caused by the cushion of air which separates the water and the glass against which it strikes.

Since the removal of the air from water increases the cohesion among the molecules, it raises the boiling-point of the liquid. In this way it has actually been raised to 275°. But when water thus freed from air does boil, it is converted into steam with explosive violence. This may be the cause of some boiler explosions, the air having been removed from the water by long boiling.

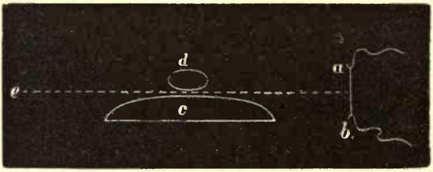
221. *The Nature of the Vessel in which Water is boiled changes the Boiling-Point.* — If a glass vessel be carefully cleansed from all grease by means of sulphuric acid, it will be found that it requires a temperature 2° or 3° higher

to boil water in it than in a tin vessel. Other experiments show that the boiling-point changes with the material of the vessel used. This is probably owing to the difference in the adhesive force between the water and the vessel.

222. *The Spheroidal State.* — If two or three drops of water be poured into a red-hot metallic cup, they gather into a globule, which runs about without boiling. In this case the water is said to be in the *spheroidal state.*

Turn a cup *c* bottom up (Figure 164), heat it to redness,

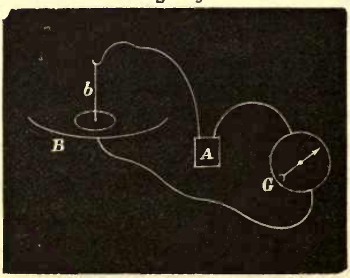
Fig. 164.



and carefully put a drop of water *d* upon it by means of a dropping-tube. Place behind the drop a piece of platinum wire *a b*, heated to a white heat by means of the electric current. It will be found, if the eye be placed at *e*, that the platinum wire can be seen between the drop and the cup, showing that the drop does not touch the cup.

That water in the spheroidal state does not touch the heated surface may be shown in another way. *B*, in Figure 165, is a heated metallic cup; *A* is a galvanic cell, one pole of which is connected with a galvanometer and the other with the platinum point *b*. The cup *B* is also connected with the galvanometer *G*. A little water is poured into the cup, and the platinum point introduced

Fig. 165.



into it. If the drop touched the cup, the circuit would now be complete; but the needle of the galvanometer does not move, showing that the circuit is incomplete, and that the drop does not touch the cup. But if the cup be allowed to cool, the needle soon swings round, showing that the drop has come in contact with the surface of the cup. At the same instant the drop is converted into a cloud of steam.

The explanation of the spheroidal state is this: as soon as the drop comes near the heated cup, steam is generated beneath it, and this steam, acting like an elastic spring, lifts the drop from the surface. As the cup cools, this spring gives way, and the water, on touching the surface, is suddenly converted into steam.

Boiler explosions are probably often caused by the water's assuming the spheroidal state, and then suddenly passing into steam.

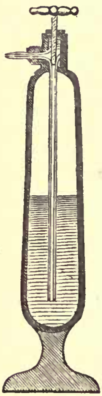
223. *Evaporation.* — If water is exposed in an open vessel at the ordinary temperature, it gradually disappears, passing off in the form of vapor. This vapor is formed slowly and only at the surface; while, in boiling, steam is formed rapidly and throughout the liquid. Water is thus evaporated into the atmosphere at all temperatures, but more rapidly as the temperature rises.

224. *Condensation.* — A gas condenses at the same point at which its liquid boils; and, as pressure raises the boiling-point of a liquid, it also raises the point at which a gas will condense. Under the combined action of pressure and cold, almost every known gas has been liquefied. The only exceptions are oxygen, hydrogen, nitrogen, nitric oxide, carbonic oxide, and marsh gas.

Faraday was the first who succeeded in liquefying gases in this way. Carbonic acid is now condensed in large quantities. Figure 166 shows a part of the apparatus invented by Thilorier for this purpose.

The gas is generated in a strong iron vessel called the *generator*, into which the materials for making the gas are put. This generator is connected with an equally strong iron vessel called the *receiver*, (shown in the figure,) which is kept cool, and, when sufficient gas has been generated, it condenses in the receiver. The two vessels are now separated, and a fresh charge introduced into the generator, and the gas is condensed in the receiver as before, until at last a large quantity of liquefied gas has been obtained.

Fig. 166.



225. *Freezing-Mixtures.* — When a solid melts, or a liquid evaporates, a large amount of heat is rendered latent. Advantage is taken of this fact to obtain an artificial reduction of temperature. One of the most common freezing-mixtures is composed of salt and pounded ice. The substance to be frozen is placed in a small vessel which is put in a larger one and packed round with this mixture. The ice rapidly melts, and in doing so absorbs a large amount of heat, thus reducing the temperature of the inner vessel.

A much greater degree of cold can be produced by the rapid evaporation of a liquid than by the melting of a solid. It will be seen from Figure 166 that in the interior of the receiver there is a tube which descends below the level of the liquid. When the cock is open, the pressure of the gas drives the liquid with great force up the tube and out through the fine nozzle in which it terminates. The liquid as it issues evaporates so fast that part of it is frozen, and the solidified gas may be collected in the form of a snow-white powder. This powder evaporates very slowly, and may therefore by proper precautions be preserved for a considerable length of time. It may also be handled with impunity, and may even be laid upon the tongue without a disagreeable sensation of cold, although its temperature is extremely low, perhaps even —106° F. The reason of this absence of the feeling of cold is want of contact between the solid and the tongue or the hand. The solid is actually in the spheroidal state.

If the solid acid be mixed with ether, it evaporates rapidly, and a great degree of cold is the result. By means of such a mixture 20 or 30 pounds of mercury may be readily frozen. If the mixture be placed under an exhausted receiver, the evaporation is greatly quickened, and a much greater degree of cold is obtained. Faraday thus reached a temperature of —166° F.

A still lower temperature, of —220°, has been obtained by Natterer by placing a mixture of liquid nitrous oxide and bisulphide of carbon in an exhausted receiver.

SUMMARY.

The heat which a body absorbs is sometimes used in changing its state. (212.)

The melting and boiling points are the same for the same substance under the same pressure ; but those of different substances are different. (213, 216.)

When a substance melts or boils, a certain definite amount of heat is rendered *latent*. The heat thus rendered latent is called the latent heat of the *liquid*, or of the *vapor*, or *gas*. (214, 217.)

The latent heat of a liquid or a vapor can be found by means of the calorimeter.

The latent heat of *water* is higher than that of any other liquid ; and that of *steam* is higher than that of any other vapor. (215, 217.)

The boiling-point of water is raised by increasing the pressure, and by freeing the water from air. (219, 220.)

When water is put into a red-hot vessel, it is prevented from coming in contact with the heated surface by a layer of steam, and is said to be in the *spheroidal state.* (222.)

Liquids evaporate at all temperatures, but more rapidly as the temperature rises. (223.)

Vapors condense at the same point as that at which their liquids boil. (224.)

In the various *freezing-mixtures*, advantage is taken of the fact that heat is rendered latent in the melting of solids and in the evaporation of liquids. (225.)

EXPANSION.

226. *Solids are expanded by Heat.* — If a brass ball which will just pass through a ring be heated, it will no longer pass through the ring. It has been expanded by the heat. In like manner all solids are found to be expanded by heat.

227. *Different Solids expand unequally for the Same Rise of Temperature.* — If a bar of iron and one of copper be riveted together and then plunged in boiling water, so that the temperature of both may be raised to the same point, the compound bar will become curved, the copper being the convex side. This is because copper is expanded more than iron for the same rise of temperature. On comparing different solids we find that scarcely any two are expanded alike by heat.

228. *Liquids are expanded by Heat.* — Fill a test-tube with water, and then close it with a rubber cork through which passes a fine glass tube. Plunge the test-tube in boiling water, and the liquid will rise in the tube, showing that it has been expanded by heat.

229. *Different Liquids expand unequally for the Same Rise of Temperature.* — Fill a second test-tube with alcohol, and plunge both into boiling water. The alcohol will rise higher in the tube than the water will, showing that it is

expanded more by the heat. Different liquids, then, expand unequally for the same rise of temperature.

230. *Gases are expanded by Heat.* — Close a pint flask with a cork through which passes a bent tube, and connect the tube with a jar inverted over water. Plunge the flask into boiling water, and bubbles of air rush over into the jar. This experiment shows that air is expanded by heat. The same is found to be true of all other gases.

231. *Different Gases expand equally for the Same Rise of Temperature.* — Fill now the same flask with hydrogen or oxygen, connect it with the same jar as before, and again plunge the flask into boiling water. Precisely the same amount of gas will pass over as at first, showing that these gases expand equally for the same rise of temperature. The same is true of other gases.

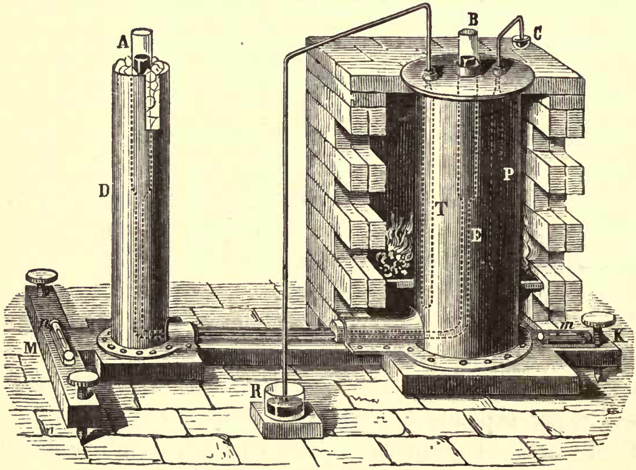
Solids, liquids, and gases are, then, expanded by heat; solids and liquids unequally, and gases equally, for the same rise of temperature.

232. *How to find the Coefficient of Expansion for Mercury.* — Copper expands .000051 of its volume for a rise of 1° Centigrade. The amount a body expands for a rise of 1° C. is called its *coefficient of expansion.* The coefficient of expansion for copper, then, is .000051.

When this coefficient is known, the expansion of any body for any given rise of temperature can be readily calculated.

A and *B* (Figure 167) are upright glass tubes connected at the bottom. Both are surrounded by metallic cases, one of which, *D*, is filled with pounded ice, and the other, *T*, with oil. The latter case is enclosed in a furnace, so that its temperature can be raised to any desired point. The density of the mercury in the tube *B* will diminish in the exact ratio of its expansion, and the temperature of the mercury in the tube *A* is always at the freezing-point. It will therefore rise in the other tube in proportion as it expands; that is, if the mercury in *B* should be expanded so as to double its volume, it would stand twice as high in that tube as in *A*, since its density would be only half as great. By noticing, then, the difference in the height of the mercury in the two tubes for any rise of temperature,

Fig. 167.



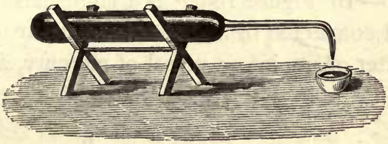
we can ascertain the expansion of the mercury; and this expansion, divided by the number of degrees the temperature has risen, will give the coefficient of expansion.

233. *How to find the Coefficient of Expansion for any Liquid.* — Let a glass bulb having a projecting tube, be filled with any liquid and be heated. The liquid will at first fall in the tube, and then begin to rise and continue to rise steadily as the temperature increases. The falling of the liquid at first is owing to the fact that the glass, being first heated, expands before the liquid does. After this the liquid expands more rapidly than the glass, and therefore rises in the tube.

The expansion of a liquid as measured in such a bulb is only its *apparent* expansion. Its real expansion is this apparent expansion *plus* the expansion of the bulb.

The expansion of the bulb can be found by means of mercury. In Figure 168 we have a bulb with a projecting tube drawn out to a fine point. This bulb is first weighed,

Fig. 168.



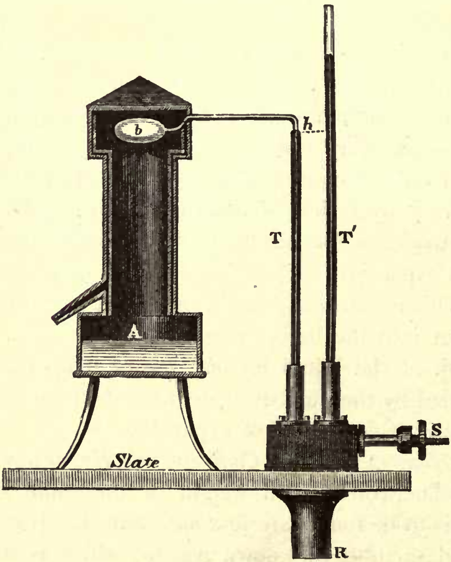
and then filled with mercury and weighed again. The difference of these weights is the weight of the mercury at the ordinary temperature. The bulb is now heated, and a part of the mercury runs out. The bulk of the mercury which runs out is equal to the excess of the expansion of the mercury over that of the bulb. Now we know the real expansion of mercury, and the excess of this over its apparent expansion, as just found, is the expansion of the bulb. This expansion, *plus* the apparent expansion of any liquid put into the bulb, gives, as we have seen, the real expansion of the liquid for any rise of temperature; and this divided by the number of degrees the temperature has risen gives the coefficient of expansion.

234. *How to find the Coefficient of Expansion for any Solid.* — The volume and weight of the solid whose expansion is to be found are first ascertained. It is then put into a glass tube, of known weight, which is filled with mercury and drawn out to a fine point. The weight of the whole, *minus* the weight of the tube and the solid, is the weight of the mercury. The whole is now heated to a certain temperature, and the mercury which runs out is weighed. Now, since we know the rate of expansion of the glass and of the mercury, we know how much mercury

should have run out had the solid not expanded at all; and the excess of the mercury which actually runs out over this amount is equal to the expansion of the solid. This divided by the number of degrees the temperature has risen gives the coefficient of expansion.

235. *How to find the Coefficient of Expansion for Air and other Gases.* — In Figure 169 *b* is a large glass bulb filled with air and connected by a glass tube with the upright tube *T*. The latter opens into a vessel of mercury, as does also

Fig. 169.



the tube *T′*. By means of the screw *S* the mercury can be kept at the same height in the two tubes. The bulb is first surrounded with melting ice, and the mercury in the two tubes is brought to the same level. The bulb is next immersed in steam, and the mercury in the tubes again brought to the same level. The difference of the heights of the mercury in the two cases is equal to the expansion of the air for a rise of temperature between 32° and 212° F., and from this we can easily find its coefficient of expansion. Since the air on expanding partially fills the tube *T*, it is necessary that the tubes *T* and *T′* should be surrounded with boiling water, in order that all the air may be kept at the same temperature.

It is found in this way that air expands .367 of its volume for a rise of temperature from 32° to 212°.

The following Table shows the expansion of several gases for this rise of temperature :—

Hydrogen	0.3661
Atmospheric air	0.3670
Carbonic oxide	0.3669
Carbonic acid	0.3710
Nitrous oxide	0.3719
Sulphurous acid	0.3903
Cyanogen	0.3877

It will be observed that hydrogen, carbonic oxide, and atmospheric air, gases which cannot be condensed and whose temperature must therefore be far above the boiling-points of their liquids, expand almost exactly alike, while the other gases, which can easily be condensed and must therefore be near their boiling-points, expand more rapidly and somewhat more unequally. This is probably because the molecules in the latter are still so near together that they exert considerable influence on one another. At a greater distance from the boiling-point the molecules may get so far apart that they exert no sensible influence upon one another. Such gases are called *perfect* gases.

236. *When a Gas is not allowed to expand, its Elasticity is increased by Heat.* — As the bulb in Figure 169 becomes heated, the expansion of the gas drives the mercury from the tube *T*. The mercury can, however, be kept at the same height by increasing the pressure upon the mercury

in the box by means of the screw *S*. This increase of pressure will also cause the mercury to rise in the tube *T'*. The difference of height in the columns of mercury in the tubes shows how much the elastic force of the gas is increased. In this way it is found that the elasticity of air when not allowed to expand is increased about .367 for a rise of temperature from 32° to 212°.

SUMMARY.

The heat absorbed by a body is used partially in pushing the molecules apart, or *expanding* it. (226.)

Different solids and liquids expand unequally, and different gases equally, for the same rise of temperature. (227, 231.)

The *coefficient of expansion* for a body is the amount it expands for a rise of temperature of 1° C. (232 – 235.)

When a gas is not allowed to expand, its elasticity is increased by heat. (236.)

CONVECTION.

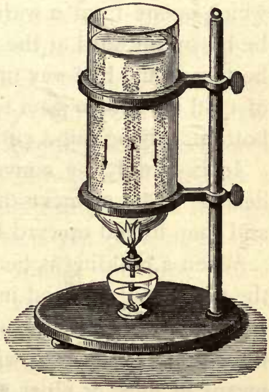
237. We have now seen that the molecules of a body are separated when it becomes heated; and, since the molecules of liquids and gases are free to move, this expansion ought, when they are heated unequally in different parts, to create currents; for the unexpanded and heavier portions will tend to displace the lighter ones and to compel them to rise. As these heavier portions become heated, they will in turn tend to rise and give place to colder portions; and so on.

These currents, of course, tend to distribute the heat, and this mode of distribution is called *convection.*

238. *Convection of Liquids.* — In Figure 170 we have a glass beaker filled with water heated by a lamp below. A

little sawdust is added to the water, and its motions show that a current is passing up the centre of the vessel and down at the sides, as indicated by the arrows in the figure. Each molecule is thus seen to come to the bottom to get heated, and then to return to the surface. It is in this way that water, which is so bad a conductor, is so readily heated when the heat is applied below.

Fig. 170.



239. *Oceanic Currents.*—Oceanic currents are produced by convection. The temperature of the sea in the tropics is about 50° higher than at the poles, and the specific gravity of the water is therefore much less. To restore the equilibrium, the warmer and lighter water of the tropical regions flows towards the poles, and the colder and denser water of the polar regions flows towards the equator. If the whole earth were covered with water of the same saltness, we should everywhere have a surface-current from the equator towards the poles, and an under-current from the poles towards the equator. But owing to the obstructions offered by the land and by the inequalities in the bed of the ocean, and to the different degrees of saltness, and therefore of density, in different parts of the sea, these two great currents are broken up into innumerable currents and counter-currents, which diversify the face of the ocean and mark out the highways of commerce.

The most remarkable of these currents is the *Gulf Stream*, which issues from the Gulf of Mexico, flows northward off the coast of the United States, and, crossing the Atlantic in a northeasterly direction, washes the western coast of Europe.

240. *Convection of Gases.* — If a lighted candle be put in a beam of solar or electric light which is thrown upon a screen by means of a lens, the currents of air which are streaming up around the flame can be readily seen.

Again, if a lighted candle be held in the crack of a door which opens from a warm into a cold room, the flame will be blown outward at the top of the door and inward at the bottom, while half-way up it will burn steadily. A current of cold air is thus seen to be passing into the room at the bottom, driving out a current of warm air at the top.

It is mainly by convection that the air in a room is heated. The air next the stove is heated and expanded, and then forced upward by the current of colder air.

When a building is heated by a furnace, this is placed in the cellar and encased in brick-work or in sheet-iron. The space between the fire-pot and the casing is connected by means of the air-box with the outer atmosphere, and by means of flues or pipes with the rooms to be heated. The air about the fire-pot first becomes heated, and is driven up through the pipes by the cold air from without.

SUMMARY.

When a gas or a liquid is heated beneath its surface, currents are produced which distribute heat by *convection.*

It is in this way that the Gulf Stream and other *oceanic currents* are produced. (237 – 240.)

THE RELATION OF WATER TO HEAT.

241. *The High Specific and Latent Heat of Water.* — Water, because of its specific and latent heat, which are higher than those of any other liquid, exerts a marked influence upon climate. It makes the transition from winter to summer and from summer to winter more gradual.

In the spring, when the snow begins to melt, a large amount of heat is absorbed from the air and rendered latent. After the snow and ice are all melted, such is the specific heat of water that it requires a great deal of heat to raise its temperature. In the fall, on the other hand, as the water cools down and freezes, it gives out all the heat which it had absorbed and rendered latent in the spring.

242. *The Irregular Expansion and Contraction of Water.* — Bodies, as we have seen, usually contract when cooled. Liquids continue to contract, not only until they are frozen, but even after freezing. Fill a test-tube with water at a temperature of 70° and close it with a rubber cork through which passes a fine glass tube. Press the cork in so that the water shall rise in the tube. Plunge the tube into a freezing mixture, and the water gradually falls until its temperature is about 39°. It then slowly rises until its temperature is 32°. It now begins to freeze, and suddenly expands. If, therefore, water at the temperature of 39° be either warmed or cooled, it expands. This temperature is hence called the *point of maximum density* of water.

This expansion of water in freezing is often illustrated by the bursting of pipes and vessels in which water is allowed to freeze. Water is the only liquid which has such a point of maximum density, and there are but very few substances which expand when they become solid. Iron is such a substance, and it is owing to this property that it is so well adapted for castings. As it solidifies, it expands so as completely to fill the mould. Bismuth expands in the same way, and also the alloy of antimony, lead, and tin, which is used for type-metal.

This irregular expansion of water is of the greatest importance. Before freezing it begins to grow lighter, so that the freezing begins at the surface; and the ice, being lighter still and also a poor conductor of heat, floats upon the water and keeps it from freezing very deep. If water continued to contract as it cooled, it would begin to freeze at the bottom, and during the winter our lakes and rivers would become solid masses of ice. This would be fatal to all animal life in the water; and, as water is a very poor conductor of heat, it would melt only to the depth of a few feet during the summer.

243. *Latent Heat of Steam and Vapor.* — Not only is the latent heat of water greater than that of any other liquid, but that of steam and watery vapor is greater than that of any other gas or vapor, hydrogen alone excepted.

244. *Heating by Steam.* — It is now quite common to warm buildings by steam. Pipes run from the boiler through the rooms to be heated, and then back to the boiler again. The steam passes from the boiler into these pipes, where it is condensed and runs back as water to the boiler. Now every pound of water converted into steam in the boiler takes up over 900 units of heat, and every pound of steam which condenses in the pipes gives out the same amount of heat into the rooms. The water is thus made to act as carrier of heat between the furnace and the room where it is wanted. As fast as it gives up the heat which it has absorbed from the furnace, it runs back to the boiler for more.

SUMMARY.

The high specific and latent heat of water tends to make the transition from winter to summer and from summer to winter more gradual. (241.)

The irregular expansion and contraction of water when heated and cooled prevents the lakes and rivers from freezing solid in the winter. (242.)

Steam has a high specific and latent heat, which becomes sensible on condensation. It is, therefore, used for heating buildings. (243, 244.)

THERMAL INSTRUMENTS.

245. *The Mercurial Thermometer.* — The ordinary thermometer is one of the most important thermal instruments, and is used, as its name implies, to measure temperature. It consists of a fine glass tube with a bulb blown upon one end of it. At the ordinary temperature the bulb and a part of the tube are filled with mercury.

In order to fill the tube with mercury, a cup of glass or india-rubber is connected with the top of the tube. This cup is filled with mercury, and the bulb heated so as to drive out a part of the air. The bulb is then allowed to cool, and a part of the mercury falls into the tube to take the place of the air driven out. This mercury is now boiled a short time, and in this way the remainder of the air is expelled. The bulb being allowed to cool again, more mercury passes in and fills both bulb and tube. The mercury is now heated up to the highest temperature which the thermometer is intended to measure, and the end of the tube is sealed air-tight by melting the glass. As the bulb cools again, the mercury falls in the tube, leaving a vacuum above it.

The next thing to be done is to *graduate* the thermometer. On the thermometer scale there are two fixed points, — that at which ice melts, and that at which water boils. These are called the *freezing-point* and the *boiling-point.*

The freezing-point is found by plunging the bulb into melting ice, and noting the position of the mercury in the tube. Melting ice is used rather than freezing water, because it is found that if water be kept perfectly still it can be cooled several degrees below the freezing-point before it congeals; while ice, at the ordinary pressure, always melts at the same temperature.

We have also seen that the boiling-point of water is affected by various circumstances. Hence the boiling-point of the scale cannot be found by plunging the bulb into boiling water. But whatever may be the temperature at which water boils, its steam always has the same temperature at the ordinary pressure. The boiling-point is then found by enclosing the bulb and tube in a steam-bath, as shown in Figures 171 and 172.

On the *Fahrenheit* scale, which is the one in common use in this country and England, the freezing-point is

Fig. 171.

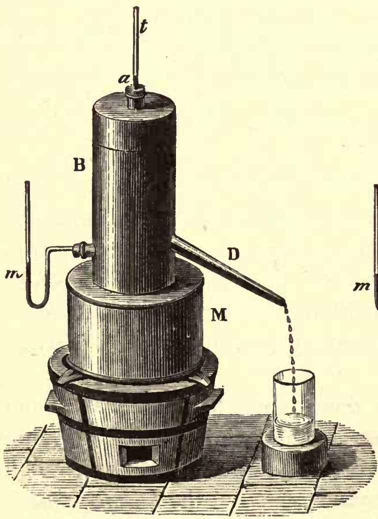
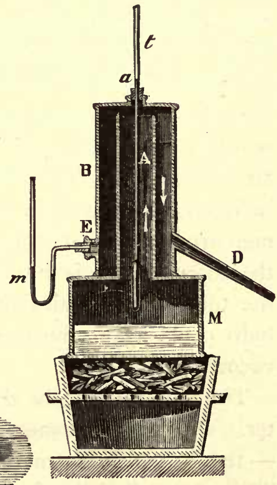


Fig. 172.



marked 32, and the boiling-point 212. The space between the two is consequently divided into 180 equal parts. The rise of temperature corresponding to the rise of the mercury through one of these parts is called one *degree*. The equal divisions are continued above the boiling-point and below the freezing-point. The scale, however, is not extended below —38° nor above 576°, since mercury freezes at one of these points and boils at the other.

On the *Centigrade* scale, which is the one commonly used in France, the freezing-point is marked 0, and the boiling point 100. 5° of this scale correspond, then, to 9° of the Fahrenheit scale.

Since the Centigrade scale is a *decimal* one, it has been adopted by most scientific men throughout the world.

A third scale, known as *Reaumur's*, is in general use in Germany. On this scale the freezing-point is marked 0, and the boiling-point 80.

246. *The Alcohol Thermometer.* — When temperatures below —38° are to be measured, alcohol is used instead of mercury. An alcohol thermometer is not, however, so accurate as a mercurial one.

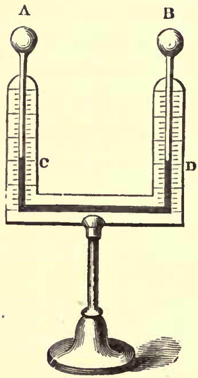
247. *The Air Thermometer.* — Mercury, as we have seen, cannot be used to measure very high temperatures. There are various ways of measuring such temperatures, but the best is by means of the *air thermometer*. The expansive force of air is very regular for all known temperatures, but it expands so rapidly that to measure the ordinary range of temperatures would require too long a tube.

The expansion of the air in the tube can be indicated by the movement of a column of liquid upon which it acts.

248. *The Differential Thermometer.* — Leslie constructed an instrument which shows the difference in temperature between two neighboring substances or places, and which is hence called the *differential thermometer*. In this instrument two bulbs, *A* and *B*, filled with air, are connected by means of a bent tube, as in Figure 173. A little colored liquid fills the lower part of this tube, and rises to the levels *C* and *D* when both bulbs are of the same temperature. But should *A* become warmer than *B*, since air

expands very much for an increase of temperature, the column of liquid will be pushed down at C and made to rise at D; and this motion will be reversed when B becomes warmer than A. Such an instrument will therefore indicate any difference of temperature with great delicacy. The liquid in the tube ought to be one which is not volatile. Sulphuric acid is frequently used.

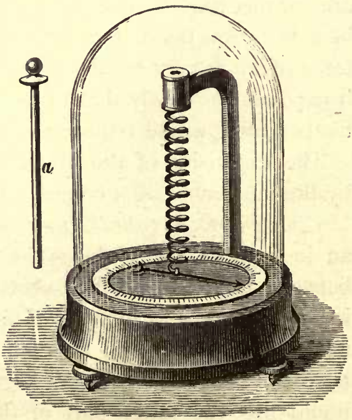
Fig. 173.



The most delicate of all differential thermometers is the thermo-electric pile, which, with its accompanying galvanometer, will be described hereafter (see *Electricity*, pages 265 and 283).

249. *Breguet's Metallic Thermometer.* — This instrument consists of a spiral (Figure 174) composed of silver, gold, and platinum, rolled together so as to form a very fine ribbon. In this state it is sensitive to an exceedingly slight change of temperature, becoming coiled or uncoiled, owing to the different expansion of the metals of which the compound ribbon is made. A needle attached to one extremity of the coil points to a scale which is graduated by the aid of an ordinary thermometer. *a* is a rod put in the axis of the spiral to keep it in place.

Fig. 174.

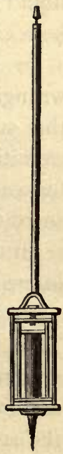


250. *Effect of Temperature upon Measures of Time.* — The rate of a clock depends upon the time in which its pendulum vibrates, and that of a watch upon the time of oscillation of its balance-wheel. Now the time of vibration of a pendulum depends upon its length; and since the change of temperature alters the length of a pendulum, it likewise alters its time of vibration. The higher the temperature, the longer does the pendulum become, and the more slowly does it vibrate. In like manner a change of temperature, by altering the dimensions of the balance-wheel of a watch and the force of the spring, will alter its time of oscillation in such a manner that it will vibrate more slowly in hot weather than in cold.

These sources of error may be obviated by means of certain compensations.

251. *Graham's Mercurial Pendulum.* — The first attempt to compensate for change of length in a pendulum was made by Graham, an English clockmaker. The rod of his pendulum, Figure 175, was made of glass, to the lower end of which was attached a cylindrical vessel containing mercury. As the glass rod expands by heat, the bottom of the vessel which contains the mercury will of course be rendered more distant from the point of suspension, but since the column of mercury resting on this base expands upwards, its centre of gravity is raised, or brought nearer the point of suspension. The lowering of the centre of gravity, due to the expansion of the glass, may thus be counteracted by the rise of the same, due to the expansion of the mercury. The correction for imperfect compensation is made by raising or lowering the cylinder of mercury by means of a screw.

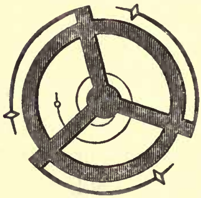
Fig. 175.



252. *Compensation Balance-Wheel.* — If the balance-wheel of a chronometer be formed, as in

Figure 176, not with one continuous rim, but with a broken rim of several separate pieces, all of which are fixed at one end and free at the other, the free ends being loaded; and further, if each piece be composed of two metals, of which the most expansible is placed without; then it is evident that on a rise of temperature the loaded ends will approach the centre. This may be so arranged as to counteract the effect produced on the rate of the chronometer by the expansion of the wheel, which carries the circumference farther from the centre.

Fig. 176.



253. *Other Effects of Expansion.* — It requires very intense pressure to produce the same change of volume in a solid or liquid body as that which is occasioned by a very small change of temperature. It follows from this that the force exerted by solids in contracting or expanding, or by liquids in expanding, must be very great. If a strong vessel be entirely filled with a liquid and then sealed tightly, the vessel will burst if there be a considerable rise of temperature.

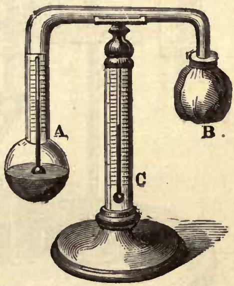
In like manner it has been calculated, that a bar of wrought iron whose temperature is 15° F. above that of the surrounding medium, if tightly secured at its extremities, will draw these together, with a force of one ton for each square inch of section, on cooling down to the surrounding temperature.

In the arts it is of great importance to bear in mind the intensity of this force, sometimes with the view of guarding against its action, and sometimes in order to make it useful. Thus, bars of furnaces must not be fitted tightly at their extremities, but must at least be free at one end. In making railways, also, a small space must be left between the successive rails. For a similar reason water-pipes and gas-pipes are fitted to each other by telescopic joints.

As an instance of the advantage which may be derived from the force of contraction, we may mention the familiar method by which tires are secured on wheels. The tire is put on hot, when it fits loosely, but as it cools it contracts and grasps the wheel with very great force.

254. *Daniell's Dew-point Hygrometer.* — A *hygrometer* is an instrument for measuring the amount of moisture in the air. The one invented by Daniell is shown in Figure 177. It is composed of two glass bulbs. The bulb *A* is more than half filled with ether, and contains a delicate thermometer plunged in the ether; the space above is void of air and of everything but the vapor of ether. The bulb *B* is covered with some fine fabric, such as muslin, upon which ether is dropped; the evaporation of the ether produces intense cold, in consequence of which the ether vapor inside *B* is rapidly condensed, and of course the ether in *A* as rapidly evaporates.

Fig. 177.

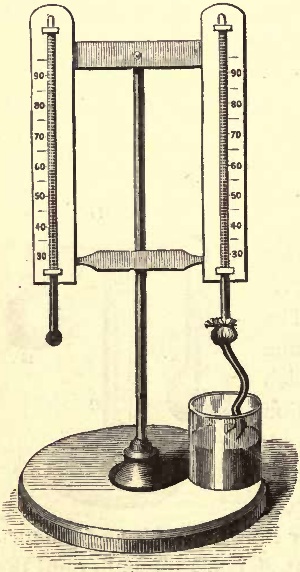


The evaporation of the ether at *A* cools the bulb until the air in contact with it sinks below the dew-point; that is, the temperature at which the moisture in the air begins to be deposited as dew. The bulb *A* is made of black glass in order that this deposition may be more readily observed. At the moment of deposition the thermometer in *A* is read. When the dew disappears, as the temperature rises, the same thermometer is also read, and the mean of these two readings is taken to indicate the dew-point. The thermometer *C* gives the temperature of the air. The nearer the dew-point is to the temperature of the air, the nearer the air is to being saturated with vapor.

255. *Wet and Dry Bulb Hygrometer.* — This instrument was devised by Mason, and consists of two thermometers

(Figure 178) placed side by side, one having a dry bulb and the other a bulb covered with muslin, kept moist by means of a string dipping in water. The wet bulb is chilled by the evaporation of the water from it, since this evaporation renders some of its heat latent. The drier the air, the more rapid the evaporation, and the greater the difference between the readings of the wet and dry bulb thermometers.

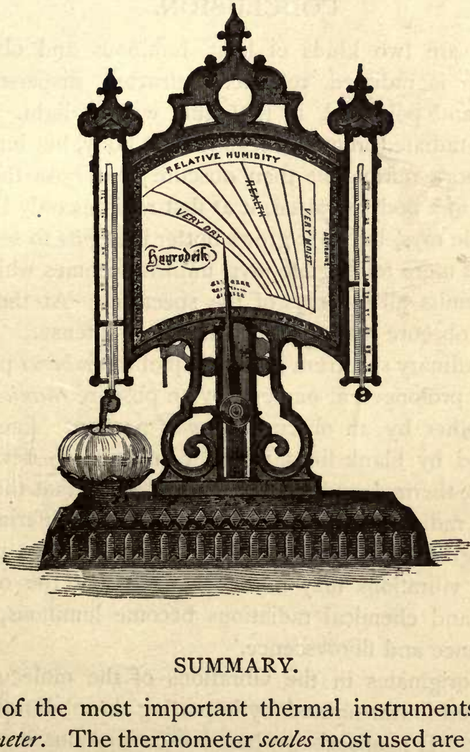
Fig. 178.



When we speak of the *humidity* of the air, we do not mean the absolute amount of vapor which it holds, but the degree of its saturation. Thus, a cubic foot of air at 32° is saturated by two grains of water; but at 68° it requires 7.5 grains to saturate it. When the air is completely saturated, its humidity is said to be 100; when half saturated, 50; when three fourths saturated, 75; and so on.

256. *Edson's Hygrodeik.* — This is shown in Figure 179, and is an improved form of Mason's hygrometer. It differs from all other hygrometers in having a dial, over which moves a pointer, showing at a glance the temperature, the degree of humidity, the absolute amount of vapor in each cubic foot of air, and the dew-point.

Fig. 179.



SUMMARY.

One of the most important thermal instruments is the *thermometer*. The thermometer *scales* most used are *Fahrenheit's*, the *Centigrade*, and *Reaumur's*. (245 – 247.)

Breguet's thermometer indicates changes of temperature by the unequal expansion of metallic ribbons. (249.)

The *differential* thermometer serves to measure the difference of temperature at two places. The most delicate differential thermometer is the *thermopile*. (248.)

The expansive power of heat may be made to regulate the rate of clocks and watches. (250 – 252.)

The *hygrometer* is an instrument for measuring the amount of moisture in the air. (254 – 256.)

CONCLUSION.

There are two kinds of heat, luminous and obscure; and each is radiated, reflected, refracted, dispersed, absorbed, and polarized, in the same way as light. They are both radiated from an incandescent body, but luminous heat is more refrangible than obscure heat. As the temperature of a body is raised, it at first radiates only the less refrangible rays, but as it grows hotter it begins to send out more and more refrangible rays, until it becomes white-hot, when it emits all the rays of the spectrum. At the same time the obscure radiations become more intense.

The ordinary spectrum is made up of a *luminous* portion, which is prolonged at one end by an obscure *chemical*, and at the other by an obscure *thermal* portion. Each part is crossed by blank lines, which, being equally devoid of luminous, thermal, and chemical power, show that the three kinds of radiations are essentially the same, differing only in refrangibility, or in the rate of vibration. The periods of these vibrations may be so changed that the obscure thermal and chemical radiations become luminous, as in calorescence and fluorescence.

Heat originates in the vibrations of the molecules of bodies, and is transmitted by imparting these vibrations to the ether. It is absorbed when these vibrations are again taken up by the molecules of gross matter. As the molecules of any body can vibrate only in certain periods, a body can radiate or absorb only certain qualities of heat.

The heat which a body absorbs raises its temperature, changes its state, and causes it to expand. It is also communicated from molecule to molecule by *conduction*, and, in gases and liquids, by currents, or *convection*.

IV.

ELECTRICITY.

ELECTRICITY.

MAGNETISM.

257. *Magnets.*—In studying Electricity it is necessary to know a few things about *magnets.*

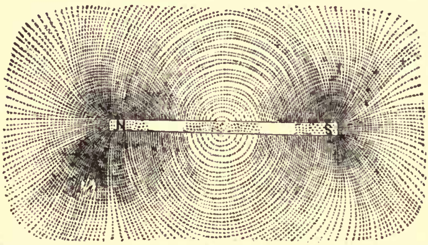
Bring one end of an ordinary bar magnet into contact with a pile of iron tacks; on removing it, a number of the tacks are carried away with it. This illustrates one of the leading characteristics of a magnet; namely, that it attracts iron. The force residing in a magnet and shown by its attracting iron is called *magnetism.*

There is a certain iron ore which has the power of attracting iron. This ore seems to have been first found near Magnesia, a city of Asia Minor. Hence the name *magnet.* Natural magnets are called *loadstones* (more properly *lodestones*), that is, stones that *lead* or draw iron.

258. *The Power of a Magnet resides chiefly at the Ends.*—If a small iron ball is fastened to a string, and moved alongside a bar magnet, it is scarcely attracted at the middle of the bar. As it approaches either end it is attracted more and more strongly, until it is brought near the end, where attraction is found much the strongest. The force of a magnet, then, resides chiefly at the ends.

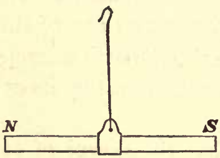
Put a piece of stiff drawing-paper over a strong magnetic bar, and strew fine iron-filings over it. Not only is the position of the magnet below shown on the paper, but the particles of iron arrange themselves in lines radiating from the poles. These lines are called *lines of magnetic force*, or *magnetic curves.*

Fig. 180.



259. *The Forces at the Opposite Ends of a Magnet act in Opposite Directions.* — Suspend a bar magnet by a string so that it can turn freely. Bring one end of a bar magnet near one end of the suspended magnet, and the latter is drawn towards it. Reverse the ends of the bar magnet, and the end of the suspended magnet is repelled. This shows that the forces at the ends of a magnet act in opposite directions.

Fig. 181.



260. *The Poles of the Magnet.* — The ends of the magnet, where the opposite forces reside, are called *poles.*

When a bar magnet is poised so that it can move freely, it takes a nearly north and south direction. One of its poles will always point to the north, and is called the *north pole.* The opposite pole is called the *south pole.* A bar magnet thus poised so as to turn freely is called a *magnetic needle.*

261. *The Earth acts like a Magnet.* — If a small needle which is free to move in a horizontal plane is placed upon a bar magnet, its south pole will always point towards the north pole of the latter. If a small *dipping needle*, that is, a

needle which is free to move in a vertical plane, is placed above the middle of a bar magnet, it stands parallel with the bar magnet. If it is moved towards the north pole of the magnet, the south pole begins to dip towards the magnet; and the farther it is moved towards this pole, the more it dips. If it is moved from the centre of the bar magnet towards the south pole, its north pole dips in the same way.

We have already seen that a magnetic needle free to move in a horizontal plane points north and south when held above the earth. It is also found that a dipping needle in the vicinity of the equator stands parallel with the plane of the horizon, and that, when carried north from the equator, its north pole dips towards the horizon; while, if it is carried south from the equator, its south pole dips towards the horizon.

It is thus found that the earth acts upon a magnetic needle like a magnet whose poles are near the poles of the earth; its south pole near the north pole of the earth, and its north pole near the south pole of the earth.

The French regard the magnetic pole of the earth near the north pole as a north pole, and the pole of the magnetic needle which points towards this pole as the south pole. The pole of the magnet, therefore, which we call the north pole, the French call the south pole, and *vice versa*.

262. *Like Poles of Magnets repel and unlike Poles attract.* — This has already been shown by the action of a bar magnet upon a dipping needle. It may be further shown by bringing the north pole of a bar magnet near the north pole of a needle, which will be repelled. On bringing the south pole of this magnet near the north pole of the needle, it will be attracted.

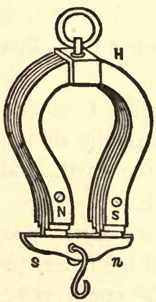
263. *Magnetism is developed in Iron or Steel by Induction.* — When a piece of soft iron is brought into contact with the pole of a magnet, it will attract other pieces of

iron, showing that magnetism has been developed in the iron by contact with the magnet. Magnetism can be developed in a piece of steel in the same way. The iron however, loses its magnetism as soon as it is taken away from the magnet, while the steel retains it. It is not necessary that a piece of iron should be brought into actual contact with the pole of a magnet in order that magnetism may be developed in it, but merely that it be brought very near the pole.

Magnetism developed in this way in a piece of iron or steel is said to be *induced.*

264. *Forms of Magnets.* — Ordinary magnets are made of steel. When straight they are called *bar magnets;* when bent into the shape of the letter U they are called *horseshoe magnets.* When several bar or horseshoe magnets (see Figure 182) are connected, they constitute a *magnetic battery.*

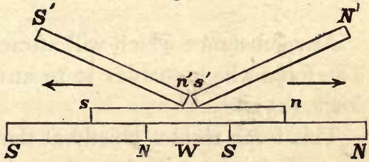
Fig. 182.



265. *The Making of Magnets.* — Magnets are often made by contact with permanent magnets by a process of *single* or *double touch.* In the former case, the steel bar to be magnetized is laid on a table, and the pole of a powerful magnet is rubbed from ten to twenty times along its length, always in the same direction. If the magnetizing pole be north, the end of the bar it first touches each time becomes north, and the end where it is taken off becomes south. The same thing may be done by putting one pole of the magnet, say the north, first on the middle of the bar, then giving it a few passes from the middle to the end, returning always in an arch from the end to the middle. The other half of the bar is then rubbed in the same way with the south pole of the magnet. The first end rubbed becomes the south, and the other the north pole of the new magnet.

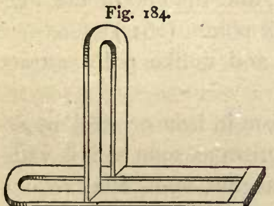
The method by *double touch* is shown in Figure 183. The bar *s n* to be magnetized is placed on a piece of wood, *W*, with its ends resting on the extremities of two powerful magnets *NS* and *SN*. Two rubbing magnets are placed with their poles near, but not touching, on the middle of *s n*, inclined to it at an angle of 10° or 15°. The two magnets are then drawn along from the middle to one end and then back to the other, and so backwards and forwards from ten to twenty times, and lifted from the magnetized bar again at the middle. Care must be taken that both ends are rubbed the same number of times, and that the lower poles of the rubbing magnets do not go beyond the ends of the bar. Both the upper and lower surfaces of the bar must be rubbed in this way, in order to magnetize it fully. A small piece of wood may be placed between the poles of the rubbing magnets to prevent contact. The position of the poles is shown in the figure by the letters; *N* or *n* meaning a north, and *S* or *s* a south pole.

Fig. 183.



For horseshoe magnets Hoffer's method is generally followed. The inducing magnet (see Figure 184) is placed vertically on the magnet to be formed, and moved from the ends to the bend, or in the opposite way, and brought round again in an arch to the starting-point. A piece of soft iron is placed at the poles of the induced magnet. Both magnets should be of the same width.

Fig. 184.



SUMMARY.

Any substance which will attract iron is called a *magnet.* The force which enables it to attract iron is called *magnetism.* (257.)

This force resides chiefly at the ends of a magnet, which are called its *poles.* It radiates from these poles in curved lines, called *lines of magnetic force*, or *magnetic curves.* (258, 260.)

The forces residing at the opposite poles of a magnet act in opposite directions. (259.)

The north pole of a dipping needle always points towards the south pole of a bar magnet, when held over it.

The earth acts upon a needle like a magnet. Its magnetic poles are situated near the poles of its axis. As we name the poles of a magnet, the magnetic pole of the earth north of the equator is a *south* pole, and the one south of the equator is a *north* pole. The French call the magnetic pole north of the equator a *north* pole, and the end of the needle which points towards it a *south* pole. (261.)

Like poles of magnets repel, and unlike poles attract each other. (262.)

A magnet can develop magnetism in iron or steel by *induction.* Soft iron loses its magnetism as soon as it is withdrawn from the influence of the magnet, while steel retains its magnetism permanently. (263.)

Ordinary magnets are made of steel. They are called, from their shape, *bar magnets*, or *horseshoe magnets.* (264.)

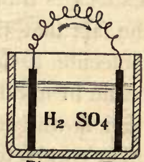
Magnets may be made by contact with other magnets, by a process of *single* or *double touch.* (265.)

NATURE AND SOURCES OF ELECTRICITY.

VOLTAIC ELECTRICITY.

266. *The Voltaic Pair.* — If in a vessel of dilute sulphuric acid we suspend a plate of zinc and a plate of platinum opposite to each other, and not in contact, we find that no chemical action whatever takes place, provided the zinc and the acid are perfectly pure. As soon, however, as the plates are united by a copper wire, as shown in Figure 185, chemical action begins. Bubbles of hydrogen gas rise from the surface of the platinum, and the zinc slowly dissolves, zincic sulphate being formed and dissolved in the liquid. The acid does not act at all upon the platinum. Such an arrangement is called a *voltaic pair* or *cell.*

Fig. 185.



If the wire connecting the plates of the pair be held over a small magnetic needle and parallel with it, the needle turns aside, and seeks to place itself at right angles to the wire, showing that a new force is developed in the wire. This force is called *electricity.*

267. *The Electric Current.* — If the vessel just used be filled with dilute muriatic acid, similar effects are produced, except that we get *zincic chloride* instead of *zincic sulphate.* "In this case the space between the plates is filled with molecules consisting of hydrogen and chlorine atoms, as indicated in Figure 186, where we have attempted to represent by symbols a single one of the innumerable lines of molecules which we may conceive of as uniting the two plates. The zinc plate, in virtue of the powerful affinity of zinc for chlorine,

Fig. 186.

attracts the chlorine atoms, which rush towards it with immense velocity; and the sudden arrest of motion which attends the union of the chlorine with the zinc has the effect of an incessant volley of atomic shot against the face of the plate. Each of the atomic blows must give an impulse to the molecules of the metal itself, which will be transmitted from molecule to molecule through the material of the plate and the connecting wire, in the same way that a shock is transmitted along a line of ivory balls."* From the fact that the electric motion is thus transmitted from molecule to molecule, it is called a *current*. It must be borne in mind, however, that the electric current is not a fluid flowing through the wire, but it is merely "a wire or other conductor filled with innumerable lines of oscillating molecules."

But these very impulses which impart motion to the metallic molecules react upon the liquid, and force back the hydrogen atoms towards the platinum plate; so that, for every atom of chlorine which unites with the zinc plate, an atom of hydrogen is set free at the platinum plate. Thus we have two atomic currents in the same liquid mass: one of chlorine atoms setting towards the zinc plate, and one of hydrogen atoms flowing in the opposite direction towards the platinum plate. Corresponding to this motion in the liquid is the peculiar atomic motion in the metallic conductor. The two are mutually dependent. The moment the connection is broken so that the motion can no longer flow through the conductor, the motion in the liquid ceases. We know nothing of the mode of the molecular motion in the metallic conductor. It is apparently allied to heat, but is capable of producing very different effects. Since we are ignorant of its nature, we

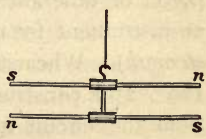
* *First Principles of Chemical Philosophy*, by Prof. Josiah P. Cooke, Jr., page 121. The remainder of § 267, together with §§ 271 – 274, is mainly condensed from the same work.

cannot be sure of the direction in which the current flows. It is possible that there may be a double current in the wire as well as in the liquid. It is always assumed, however, as a matter of convenience, that the current flows from the platinum plate through the wire to the zinc, and thence back through the liquid to the platinum.

268. *The Galvanometer.* — We have seen that the electric current has power to deflect a magnetic needle. If the wire is wound once round a needle, it is found that the deflection is greater than when it passes merely over or under it. When the wire is wound a number of times around the needle in the form of a coil, the deflection is greater still. In this case we get virtually as many currents to act upon the needle as there are turns in the coil. A needle placed within or above such a coil gives by its deflection a ready means of measuring the strength of the current. Such an arrangement is called a *galvanometer.*

269. *The Astatic Needle.* — A needle may be rendered still more sensitive to the action of the current by combining it with a second needle of the same strength, with its poles reversed. The second needle serves to neutralize the *directive* power of the earth, so that the needles will have no tendency to point north and south. Such a combination is shown in Figure 187, and is called an *astatic needle* (from a Greek word meaning *unsteady*), that is, one *having no directive power.*

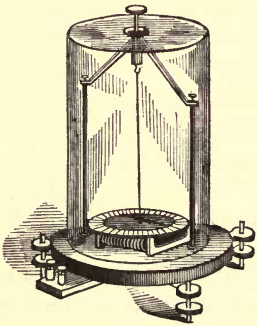
Fig. 187.



A galvanometer in which an astatic needle is used is called an *astatic galvanometer.* One needle is always placed within the coil, and the other above it.

A very delicate instrument of this kind is shown in Figure 188. The astatic needle is placed within a coil of fine copper wire carefully insulated with silk, and is suspended by a cocoon thread to a hook supported by a brass frame. It hangs freely without touching the coil, and the upper needle moves on a graduated circle. The whole is enclosed in a glass case, and rests on a stand supported by three levelling-screws.

Fig. 188.

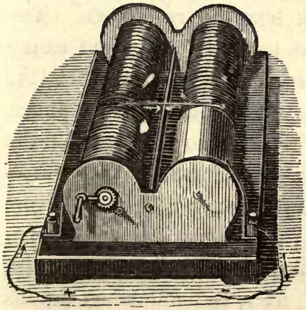


When the direction of the current is changed, the needle of the galvanometer turns the opposite way; hence the galvanometer serves to ascertain the *direction* of the current, as well as its strength.

270. *Electrical Conducting Power or Resistance.* — Some materials transmit the electric current more readily than others, since their molecules yield more readily to this peculiar form of molecular motion.

An instrument used to measure the relative conducting power of different substances is called a *rheostat* (that is, an instrument for making the *current steady*, or *of uniform strength*). Wheatstone's rheostat is represented in Figure 189. It is constructed so as to introduce into or withdraw from the circuit a considerable amount of highly resisting wire, without stopping the current. It consists of two cylinders, one of brass, the other of well-dried wood, turning on their axes by a crank. The wooden cylinder has a spiral groove cut into it, in which is placed a fine metallic wire; the brass cylinder is smooth. The end of the wire attached to the wooden cylinder is connected by means of a brass ring with a binding-screw for the attachment of a battery wire. A metallic spring pressing against the brass cylinder is connected with the other binding-screw. If now a current be sent through the wire, it will pass through all that portion of it which is wound at the

Fig. 189.



time upon the wooden cylinder, but it will not pass through the portion wound upon the brass cylinder, but through the cylinder instead, since the latter is a better conductor than the fine wire. The wire wound upon the brass, then, is withdrawn from the circuit.

When the rheostat is to be used, all the wire is wound upon the wooden cylinder, and put into the circuit along with a galvanometer. If now the resistances of two wires are to be tested, the galvanometer is read before the first is put into the circuit. After it is introduced, the needle falls back in consequence of the increased resistance, and then as much of the rheostat wire is withdrawn from the circuit as will bring the needle back to its former place. The quantity thus withdrawn is shown by a scale, and is obviously equal in resistance to the wire introduced. The first wire is then removed, and the second wire is tested in the same way as the first. If 40 inches were withdrawn in the first case, and 60 inches in the second, the resistance offered to the current by the first wire is to that offered by the second as 40 is to 60; or, in other words, the former is two thirds of the latter.

By means of the rheostat it has been proved that *the resistances of wires of the same material and of uniform thickness are in the direct ratio of their lengths, and in the inverse ratio of the squares of their diameters.* Thus a wire of a certain length offers twice the resistance of its half, thrice that of its third, and so forth. Again, wires of the same metal, whose diameters are in the ratio of 1, 2, 3, etc., offer resistances which are to each other as 1, $\frac{1}{4}$, $\frac{1}{9}$, etc. Therefore, the longer the wire, the greater the resistance; the thicker the wire, the less the resistance. The same holds true of liquids, but not with the same exactness. The following, according to Becquerel, are the *specific resistances* of some of the more common substances, or the resistance which a wire of each, so to speak, of the same dimensions, offers at the temperature of 54° F.:— Copper, 1; silver, 0.9; gold, 1.4; zinc, 3.7; tin, 6.6; iron, 7.5; lead, 11; platinum, 11.3; mercury (at 57°), 50.7. For liquids, the resistances are enormous compared with metals. With copper at 32° F. as 1, the following liquids stand thus: saturated solution of blue vitriol at 48°, 16,885,520; ditto of common salt at 56°, 2,903,538; white vitriol, 15,861,267; sulphuric acid, diluted to $\frac{1}{11}$, at 68°, 1,032,020; nitric acid at 55°, 976,000; distilled water at 59°, 6,754,208,000. Gases offer even greater resistance to the current, so that they are virtually non-conductors.

271. *Ohm's Law.* — The force of the current must depend upon the power which the moving atoms exert against the zinc plate. The effect of these atomic blows must be determined, in the first place, by the chemical force which draws the atoms towards the plate. This force is called the *electro-motive* force of the voltaic pair. But, in the second place, each moving atom is but one of a long line of similar atoms which it drags along behind it, while an equal line of dissimilar atoms is pushed back in the opposite direction. These lines of atoms act as so much *dead weight* to resist the atomic motion, and to lessen the effect of the atomic blows. In the third place, each line of moving molecules in the liquid is connected with a line of vibrating molecules in the wire, and forms with it a continuous chain so connected that the amount of motion must be equal at all points. Thus the resistance in the conducting wire reacts upon the whole chain, and lessens the effect of the atomic blows upon the zinc plate. What is

true of each line is true of all the lines in the electric current. This current is kept up by the chemical activity at the zinc plate. This activity is sustained by the electro-motive force, but impeded by the resistance of the liquid and the wire. Evidently then the power of the current is *directly proportional to the electro-motive force which sustains the motion, and inversely proportional to the sum of the resistances throughout the circuit.* If we represent the power of the current by P, the electro-motive force by E, the resistance in the conducting wire by R, and the resistance in the liquid by r, we shall have

$$P = \frac{E}{R + r}$$

The principle embodied in this formula is known as *Ohm's law.*

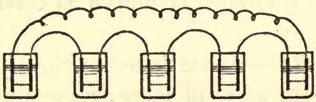
272. *Quantity and Intensity.* — If we increase the size of the plates in the voltaic pair, we shall increase the number of lines of moving molecules in the current. When these plates are connected by a thick metallic conductor, so that there shall be little resistance outside the liquid, all the lines of moving molecules will be excited to the greatest activity which the pair can give. We thus obtain a current of very great *volume*, and flowing with all the force which a single pair is capable of maintaining. The moment, however, we attempt to force this current through a great length of wire, we interpose a resistance to the atomic motion which tends to reduce the chemical activity; and as this resistance must increase with the *volume* of the motion, it will reduce the chemical activity to what it would be with a plate of much smaller size and giving a current of much less volume. By increasing the size of the plate, then, we increase the power of the current only when there is little resistance outside the liquid. We thus obtain a current composed of many moving lines of molecules, —

that is, of great *volume*, or *quantity*, but the molecular motion has little *intensity*, or *power of overcoming resistance.*

The *quantity* of the current, then, is the *volume* of the molecular motion; while the *intensity* is the *energy* of this motion.

It is evident that we can increase the intensity of the current only by increasing the chemical activity, or the electro-motive force. This may be done to a certain extent by using pairs in which there are more powerful affinities between the plate and the liquid. The electro-motive force may, however, be increased to almost any extent by using a number of pairs, and connecting them as shown in Figure 190. The platinum plate of the first cell is united with the zinc of the second, and so on to the last, whose platinum plate is united with the zinc of the first. Such a combination is called a *galvanic* or *voltaic battery*, and the current from such a battery has a much greater power of overcoming resistance than that from any single cell, however large. In a single cell the motion throughout any single line of molecules is sustained by the chemical energy at only one point, but in the battery it is reinforced at several points, — that is, at every zinc plate. Where before we had a single atomic blow, we have now a number which send their united energy along one and the same line. The electro-motive force, then, is increased in proportion to the number of cells; and the power of the current would be increased in the same proportion, were it not for the fact that the current has to traverse a greater extent of liquid. If we use n cells, both the electro-motive force, E, and the liquid resistance, r, become n times as great, while the resistance

Fig. 190.



in the wire, R, remains the same. Ohm's formula then becomes

$$P = \frac{nE}{nr + R}$$

This formula shows at once that when the exterior resistance, R, is little or nothing, we gain little or nothing by increasing the number of cells, for $\frac{nE}{nr}$ is equal to $\frac{E}{r}$. If, on the contrary, R is very large, there is great gain in using a number of cells, for we increase the numerator of the fraction much more rapidly than the denominator.

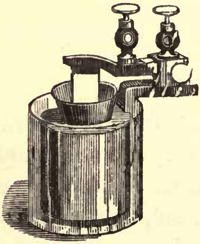
273. *The Construction of Cells.* — A voltaic pair may be constructed of any two metals, provided they are unequally acted upon by the liquid used. The greater the difference in this respect, the better. Practically, sulphuric acid is found to be the best liquid, and zinc the best material for the *active* plate.

The zinc of commerce, however, contains impurities, which give rise to what is called *local action*, and cause the zinc to dissolve in the acid when the battery is not in action. This local action can be prevented by *amalgamating* the zinc, that is, coating its surface with mercury. "The mercury on the surface of the zinc plate acts as a solvent, and gives a certain freedom of motion to the particles of the metal. These, by the action of the chemical process, are brought to the surface of the plate, while the impurities are forced back towards the interior, so that the plate constantly exposes a surface of pure zinc to the action of the acid." (See Appendix, Note 7.)

In the second place, "the hydrogen gas, which, by the action of the current, is evolved at the platinum plate, adheres strongly to its surface, and with its powerful affinities draws back the lines of atoms moving towards the zinc plate, and thus diminishes the effective electro-motive force. Moreover, after the battery has been working for some time, the water becomes charged with zincic sulphate; and then the zinc, following the course of the hydrogen, is also deposited on the surface of the platinum, which after a while becomes, to all intents and purposes, a second zinc plate, and then, of course, the electric current ceases."

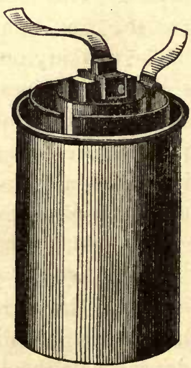
274. *Grove's Cell.* — Both these difficulties are overcome in *Grove's Cell*, shown in Figure 191. It consists of a hollow cylinder of zinc immersed in a vessel of dilute sulphuric acid. Within the zinc cylinder is put a small cylindrical vessel of porous earthen-ware, filled with the strongest nitric acid, and in this hangs the platinum plate. "The walls of the porous cell allow both the hydrogen and the zinc atoms to pass freely on their way to the platinum plate, but the moment they reach the nitric acid they are oxidized, and thus the surface of the platinum is kept clean, and the cell in condition to exert its maximum electro-motive power."

Fig. 191.



275. *Bunsen's Cell.* — If in Grove's cell we substitute for the platinum a plate of dense coke, such as forms in the interior of gas retorts, we get a very much cheaper cell of nearly equal power. The use of gas-coke was first suggested by Prof. Bunsen, and this cell is therefore called *Bunsen's Cell.* It is represented in Figure 192.

Fig. 192.



276. *Daniell's Cell.* — This cell is shown in Figure 193. The outer vessel is of copper, and serves as the passive plate. Inside this is a vessel of porous earthen-ware, containing a rod of zinc. The space between the copper and the porous cup is filled with a solu-

tion of blue vitriol, which is kept saturated by crystals of the salt lying on a perforated shelf. The porous cup is filled with dilute sulphuric acid. The porous partition keeps the fluids from mingling, but does not hinder the passage of the current. The blue vitriol which is in contact with the passive plate serves to take up the hydrogen. There are two other reasons for putting the sulphuric acid within the porous cup: (1.) if the sulphuric acid came in contact with the copper, it would tend to act upon it as well as upon the zinc, and thus to diminish the electro-motive force; (2.) the zincic sulphate formed is thus kept from coming in contact with the copper. If it were allowed to come in contact with the copper, it would be decomposed by the current passing through the cell, and zinc would be deposited on the copper; and both plates would soon be virtually of the same metal.

Fig. 193.

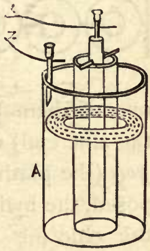


Fig. 194.

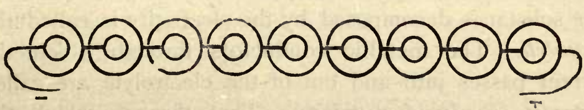


Fig. 195.

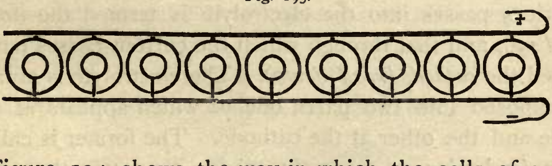
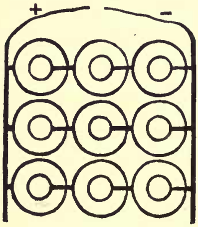


Figure 194 shows the way in which the cells of a battery are connected in order to get the greatest possible *intensity* of the electric force; Figure 195 the way in which they are connected to get the greatest *quantity*. In the latter case, since the zincs are all connected together,

Fig. 196.



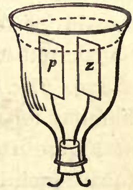
they form virtually one large plate; and the same is true of the platinums. When considerable intensity as well as quantity is desired, the two forms are combined, as shown in Figure 196.

277. *Electrolysis.* — If two strips of platinum be hung opposite each other in a cup filled with muriatic acid, and one of them be connected with the *negative pole* (that is, the zinc end) of the battery, and the other with the *positive pole* (the platinum end), the muriatic acid will be decomposed, the hydrogen passing towards the negative pole, and the chlorine towards the positive pole. Here are two atomic currents flowing in opposite directions, just as in the liquid between the plates in the voltaic pair. It is found to be true, in general, that when any compound liquid, which is a conductor of electricity, is introduced into the circuit, it is similarly decomposed. This decomposition of a substance by electricity is called *electrolysis.* The literal meaning of the word is *loosening by electricity.* The substance decomposed by the electricity is called the *electrolyte.* The metallic conductors through which the current passes into and out of the electrolyte are called *electrodes* (*roads of electricity*). That through which the electricity passes into the electrolyte is termed the *anode* (*road up*), and that through which the current passes out is termed the *cathode* (*road down*). The electrolyte is always decomposed into two parts, one of which appears at the anode and the other at the cathode. The former is called the *anion* (*going up*, or *to the anode*); the latter, the *cation* (*going down*, or *to the cathode*).

278. *The Electrolysis of Cupric Sulphate.* — If two electrodes of platinum (Figure 197) be introduced into a solution of cupric sulphate (blue vitriol), bubbles of gas rise

from the anode. This gas may be collected by filling a test-tube with the solution of cupric sulphate, and inverting it over the anode. On testing the gas, we find it to be oxygen. On removing the cathode from the solution, we find it to be coated with copper. If one of the electrodes be of platinum and the other of copper, and the platinum be made the anode, the result is the same. If, however, the copper be made the anode, the cathode is still coated with copper, but no gas escapes from the anode.

Fig. 197.



The most probable explanation of the above facts is as follows.

The electric current decomposes the cupric sulphate into copper and SO_4. This action may be expressed by an equation thus:—

$$CuSO_4 = Cu + SO_4.$$

Copper, appearing at the cathode, is the *cation;* and SO_4, appearing at the anode, is the *anion.*

When the anode is platinum, the anion acts upon the water of the solution, uniting with its hydrogen and setting its oxygen free.

$$H_2O + SO_4 = H_2\,SO_4 \text{ (sulphuric acid)} + O.$$

So that the escape of the oxygen gas in this case is due to a *secondary action*, which is purely chemical.

When the anode is of copper, the anion, instead of acting upon the water, acts upon the anode itself.

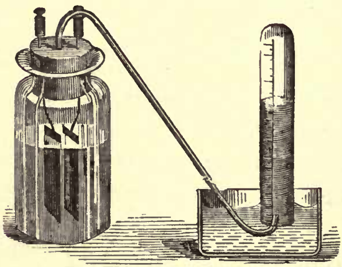
$$Cu + SO_4 = CuSO_4.$$

Hence no oxygen escapes in this case, but cupric sulphate is formed as rapidly as it is decomposed; so that the solution always remains of the same strength. The anode is gradually eaten away and transferred to the cathode.

When any compound containing a metal is decomposed by electricity, the metal always appears at the cathode; and if the anode is of the same metal, the solution always remains of the same strength, while the anode is gradually transferred to the cathode.

279. *The Voltameter.* — This instrument was invented by Faraday for testing the strength of a current. It is shown in Figure 198. Two platinum plates, each about half a square inch in size, are placed in a bottle containing water acidulated with sulphuric acid; the plates are soldered to wires which pass up through the cork of the bottle and terminate in binding-screws; a glass tube fixed into the cork serves to discharge the gas formed within. When the binding-screws are connected with the poles of a battery, the water in the bottle begins to be decomposed, and hydrogen and oxygen are set free. If now the outer end of the discharging tube be placed in a trough of mercury, and a small graduated bell-glass, likewise filled with mercury, be placed over it, the mixed gases rise into the bell-glass. *The quantity of gas given off in a given time measures the strength of the current.*

Fig. 198.



SUMMARY.

The electric current is a line of oscillating molecules, set in motion in the voltaic cell by the chemical activity at the zinc plate. (258.)

The *galvanometer* measures the strength of this current; and the *rheostat*, the resistance of the conductor. (259, 261.)

The power of the current equals the electro-motive force divided by the sum of the resistances throughout the circuit. (271.)

The *quantity* of the current is the *volume* of the molecular motion; its *intensity* is the *energy* of this motion. (272.)

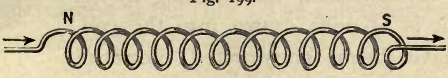
In a voltaic cell it is necessary to have two plates, and a liquid which acts upon one more strongly than upon the other. The most powerful cells are *Grove's* and *Bunsen's*. (273–275.)

When any compound liquid, which is a conductor of electricity, forms a part of the circuit, it is decomposed. This decomposition by electricity is called *electrolysis*. It is usually attended by a *secondary action*, which is purely chemical. (277.)

RELATIONS OF ELECTRICITY TO MAGNETISM.

280. *The Current can make Iron Magnetic.* If a part of the wire of the circuit be wound into a coil, and a piece of soft iron be placed inside this coil, it becomes strongly magnetic while the current is passing; as may be shown by bringing bits of iron near the ends of the iron inside the coil. Such a magnet is called an *electro-magnet*.. The coil is called a *helix*. If the coil is a left-hand coil (see Figure 199), the end at which the current enters the coil will be

Fig. 199.

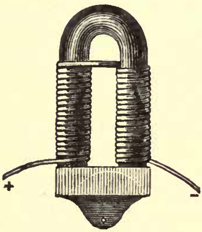


found by means of the magnetic needle to be the north pole; so that, by reversing the current, the poles of the electro-magnet will be reversed. If the coil is a right-hand one (see Figure 200), the end at which the current enters is found to be the south pole.

Fig. 200.

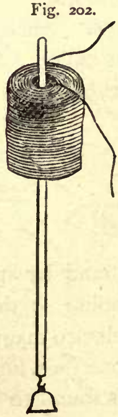
When the current is broken, the soft iron instantly loses its magnetism, and the bits of iron no longer cling to it. If a steel rod is used, instead of a soft iron one, it retains its magnetism after the current is broken. If the wire is wound around the iron in several layers, the strength of the magnet is greatly increased.

Fig. 201.



The strongest electro-magnets are of the horseshoe form. They far exceed ordinary magnets in power. Small electro-magnets have been made which support 3500 times their own weight, and large ones which hold up a weight of 2500 pounds. These magnets are much stronger when provided with a *keeper*, or *armature*, that is, a piece of soft iron which connects the two poles, as shown in Figure 201.

Fig. 202.



281. *The Wire through which a Current is passing is a Magnet.* — If the current be sent through a coil such as is shown in Figure 202, and the end of a rod of soft iron be brought near the opening in the centre, it is at once drawn into the coil. Coils have been constructed powerful enough to draw up and sustain a weight of 600 pounds.

The electric current, then, not only develops magnetism in soft iron, but the coil itself, through which the current is passing, is magnetic. Fine iron-filings will adhere to the wire which joins the poles of a battery, showing that any wire through which the current is flowing is magnetic.

282. *Magneto-electricity.* — We have now seen that the electric current has power to move a magnet.

Excite an electro-magnet, hang the rod of a lifting-coil to one of its poles, attach the lifting-coil to the galvanometer, and quickly slip it over the rod, which is now a magnet. The needle promptly turns aside, but soon comes back to its former position. Now quickly slip the coil off from the rod, and the needle turns in the opposite direction.

This experiment shows that an electric current is developed when a continuous conductor is moved near a magnet. A current thus originated by a magnet is said to be *induced* by it, and the electric force thus induced is called *magneto-electricity*.

We have seen that the electric current renders a piece of soft iron placed inside a helix temporarily magnetic.

Attach the lifting-coil to the galvanometer, place the rod within the coil, and bring it quickly in contact with the pole of an excited electro-magnet. Magnetism is developed in the rod, and a current in the wire of the coil, as is shown by the galvanometer. The needle soon returns to its former position. Now quickly detach the rod and coil from the magnet. The rod loses its magnetism, and a current is developed in the coil. The galvanometer shows that its direction is the opposite of that of the former current.

It appears, then, that a current may be developed in a conductor by using either a constant or a variable magnet. When a constant magnet is used, the current is developed by changing the relative positions of the magnet and the conductor ; when a variable magnet is used, by changing the strength of its magnetism.

SUMMARY.

The wire through which a current flows is magnetic.

When a piece of soft iron is placed inside a helix, and a current sent through the wire, magnetism is developed in the iron. A magnet made in this way is called an *electro-magnet*, and is much stronger than an ordinary magnet. (280, 281.)

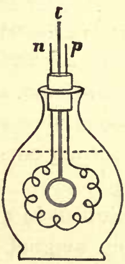
Electricity can be developed by magnetism, either by moving a conductor near a constant magnet, or the magnet near the conductor; or by changing the strength of the magnetism in a magnet which is near a conductor.

Electricity developed by magnetism is called *magneto-electricity*. (282.)

THE RELATION OF ELECTRICITY TO HEAT.

283. *Heat developed by the Current.* — When a current passes through fine wire, an intense heat is produced, sufficient in some cases to bring it to a white heat, and even to fuse platinum wire. Experiments upon the heating effects of the current may be made by the apparatus shown in Figure 203. The bottle is filled with alcohol, which is a non-conductor. The thick wires n and p are connected with a battery, and within the bottle they are joined with a fine spiral wire, surrounding the bulb of a delicate thermometer, t. When the circuit is closed, the heat developed is communicated to the alcohol, and thus to the thermometer. It is found that if the wire be kept the same, or of the same resistance, the heat is in proportion to the square of the strength of the current. Thus, if a current of a certain strength

Fig. 203.



raises the thermometer 1° in a minute, a current of twice the strength will raise it 4° in a minute.

Again, if by means of a rheostat the strength of the current be kept at the same point, and wires of different resistance be put into the bottle, the heat developed is in proportion to the resistance of the wire. Thus, if with a wire of a certain resistance the thermometer be raised 1° per minute, it will be raised 2° per minute with a wire of double the resistance.

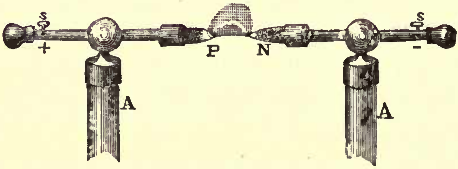
Hence *the heat developed in a conducting wire by an electric current is proportional to the square of the strength of the current, and to the resistance offered by the wire.*

A very pretty illustration of the fact that the heat is proportional to the resistance is furnished by a chain, the alternate links of which are made of silver and platinum. When a current of sufficient strength is sent through the chain, the silver links remain black, while the platinum links become red hot.

284. *The Voltaic Arc.* — When the ends of two wires which form the poles of a powerful battery are made to touch, and then are separated for a short distance, the current does not cease with the separation, but forces its way through the intervening air, with an intense evolution of light and heat. The heat is sufficient to melt the most refractory metals, and therefore some substance rivalling the metals in conducting power, but much more infusible, must be found to act as the poles under such circumstances. The various forms of carbon are well suited to this purpose; but the best, both for conducting power and durability, is the coke formed in the retorts in the distillation of coal-gas. Figure 204 represents a simple arrangement for producing the electric light. The carbon points, *P*, *N*, are fixed into hollow brass rods, which slide in the heads of the glass pillars, *A*, *A*, and are connected with the battery by binding-screws, *s*, *s*. The points are made to

touch, and the current is sent through the rods; the points are then separated a little, when a light appears

Fig. 204.



between them rivalling that of the sun in purity and splendor. On examination this light is found to arise chiefly from the intense whiteness of the tips of the carbon points, and partially from an arch of flame extending from one to the other. The positive pole is the brighter and hotter, as is shown by the fact that, on intercepting the current, it continues to glow for some time after the negative pole has become dark.

While the light is kept up, a visible change takes place in the condition of the poles. The positive pole suffers a loss of matter; particles of carbon pass from it to the negative pole, some reaching it, and some being burned by the oxygen of the air on the way. There is a similar loss, though to a much less extent, at the negative pole. The positive pole becomes hollowed or blunted, and the negative remains pointed.

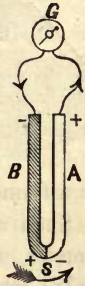
The heat of this arch of flame, or *voltaic arc*, as it is called, is the most intense that can be produced, and is due to the great resistance the current meets in traversing the air. Platinum melts in it like wax in the flame of a candle. Quartz, the sapphire, magnesia, lime, and other substances equally refractory, are readily fused by it. The diamond becomes white hot, swells up, fuses, and is reduced to a black mass resembling coke.

The electric light is caused, not by the combustion of the carbon, but by its incandescence. The light can consequently be produced in a vacuum, and below the surface of water, oils, and other non-conducting liquids. It is thus quite independent of the action of the air.

With a battery of some fifty Bunsen's cells, a light is produced of very great brilliancy; but when very great power is to be obtained, twice or thrice that number must be employed.

285. *Thermo-electricity.* — When the point of junction of any *two* metals is heated, a current is always produced. When a bar of antimony, *A*, is soldered to a bar of bismuth, *B* (see Figure 205), and their free ends are connected with a galvanometer, *G*, a current passes from the bismuth to the antimony when the junction is heated. When *S* is cooled by applying ice, or otherwise, a current in the opposite direction is produced. Such a combination of metals is called a *thermo-electric pair.* The electricity so developed is called *thermo-electricity* (*heat* electricity).

Fig. 205.

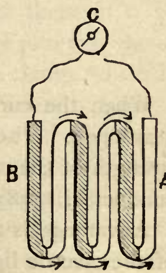


Metals like antimony and bismuth, which have a crystalline structure, are best suited for a thermo-electric pair.

Farmer's alloy (of zinc and antimony) forms a much more powerful pair with bismuth than antimony itself does.

286. *Thermo-electric Battery.* — One bismuth-antimony pair has very little power. To obtain a stronger current, several pairs are united, as shown in Figure 206. The heat in this case must be applied only to one row of soldered faces. The strength of the current depends on the difference of temperature of the two sides; and to increase it to the maximum the one series must be kept in ice or in a freezing mix-

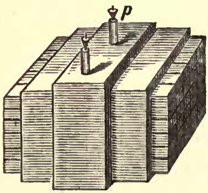
Fig. 206.



ture, whilst the other is exposed to an intense heat. As in the galvanic battery, the electric force is proportionate to the number of pairs. At best, however, it is small, and the galvanometer used to measure it must be a very delicate one.

When a great many pairs are formed into a battery, they are usually arranged as shown in Figure 207, which represents one of thirty pairs. The odd faces, 1, 3, 5, etc., are exposed on one side, and the even faces, 2, 4, 6, etc., on the other. The terminal bars are connected with the binding-screws. The interstices of the bars are filled with gypsum to keep them separate, and the whole is put in a frame of non-conducting material.

Fig. 207.



Such a battery, in connection with a sensitive galvanometer, forms the most delicate differential thermometer (248) which has yet been constructed. So long as the opposite faces are exposed to the same temperature, no current is produced; but if the temperature of one side becomes higher than that of the other, a current is at once indicated. If the hand, for instance, be brought near one side, the needle shows a current; or if a piece of ice be held near, a current is also shown, but moving in the opposite direction.

SUMMARY.

When the current passes through a conductor, heat is developed. The heat is proportional to the square of the strength of the current, and to the resistance offered by the conductor. (283.)

Advantage is taken of the same fact in the development of the electric light. (284.)

Heat has power to develop electricity in a combination of different metals. Electricity thus generated is called *thermo-electricity*. (285.)

The thermo-electric pile is a very sensitive differential thermometer, since a current is developed by the slightest difference of temperature between the two faces. (286.)

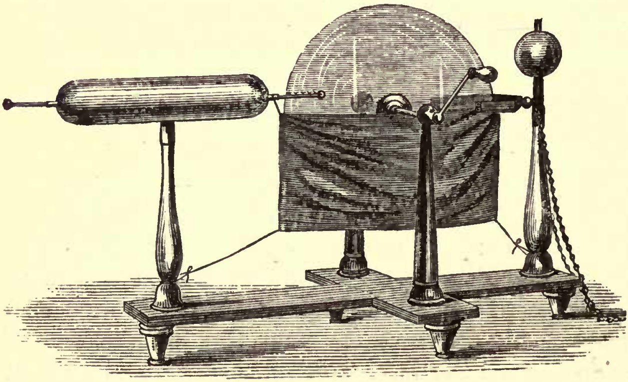
FRICTIONAL ELECTRICITY.

287. *Electricity developed by Friction.* — When a cat's back is stroked on a cold, dry day, in a darkened room, sparks are obtained which at once indicate the development of electricity. If a well-dried rod of glass or gutta-percha be rubbed with a piece of silk or flannel, similar sparks appear. Hence electricity may be developed by friction. Such electricity is called *frictional electricity*. It is found by experiment that, when any two dissimilar bodies are rubbed together, electricity is developed ; but when the substances are conductors of electricity, the force thus developed passes off silently through the hands and body. In order to detect it, the substances rubbed together must be held by *insulating* handles, that is, handles which do not conduct electricity.

288. *The Electrical Machine.* — An apparatus for generating frictional electricity is called an *electrical machine*. The one shown in Figure 208 consists of a thick plate of glass turned by a crank. At one end there is a glass standard surmounted by a brass ball. From this standard project two brass strips in the form of a clamp, which hold the rubbers against the glass plate. These rubbers are pieces of wash-leather or woollen cloth, covered with an amalgam of mercury, lead, and tin. At the opposite end, on a glass support, is a long cylinder of brass with rounded ends. This cylinder is the *prime* or *positive* conductor. The brass ball connected with the rubber is the *negative*

conductor. The plate and conductors of the machine must be well insulated. In dry and frosty weather glass

Fig. 208.



insulates very well ; at all other times it becomes covered with a scarcely visible layer of moisture, which very much impairs its insulating power. The deposition of moisture is greatly lessened by coating the glass with shellac.

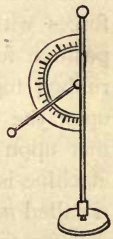
289. *Quantity and Intensity of Frictional Electricity.* — With a medium-sized electrical machine of this kind, sparks are readily obtained two inches long by presenting a conducting substance to the ball of the prime conductor. Very large machines will give a spark two feet in length. Frictional electricity, then, must have great intensity, in order to traverse so great a distance of a non-conducting substance like the air. Its quantity, on the other hand, is next to nothing. This is shown by connecting the positive conductor with one end of the wire of a moderately delicate galvanometer, and the negative conductor with the other end, and working the machine. The needle will be deflected only one or two degrees. The great tension (or intensity) and the small quantity of frictional electricity place it in striking contrast with voltaic electricity.

The positive conductor of an electrical machine answers to the positive pole of a galvanic battery, and the negative conductor to the negative pole, and the friction on the plates to the chemical action in the cells. With the galvanic battery an enormous quantity of electricity is obtained of slight tension; with the electrical machine, a small quantity of enormous tension.

290. *The Electroscope.* — If a pith ball hung by a silk thread from a glass rod be brought near the ball of a prime conductor, it is at first attracted and then repelled. This power of attracting light bodies is one of the most striking features of frictional electricity. It grows out of its high tension, and it furnishes the most ready means of detecting the presence of this electricity, as the needle furnishes the most ready means of detecting the presence of voltaic electricity.

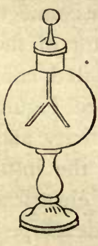
An instrument constructed on this principle for the detection of frictional electricity is called an *electroscope*.

Fig. 209.



The *pith-ball electroscope* (Figure 209) consists of a brass conducting-rod supporting a graduated semicircle, in the centre of which is a movable index made of very light wood, with a pith ball at the end. When it is attached to the prime conductor of the machine, the pith ball is repelled as soon as the plate is turned.

Fig. 210.



The *gold-leaf electroscope* (Figure 210) is a more delicate instrument. It consists of a hollow glass ball, the neck of which is covered by a brass cap. Through this cap, but insulated from it, passes a brass rod having a brass ball at its upper end and two narrow strips of gold-leaf suspended from its lower end. If the brass ball be brought near a body charged with electricity, the strips of gold-leaf repel each other, as in the figure.

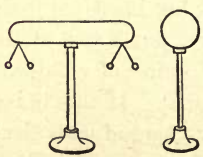
291. *The Electrical Forces on the Positive and Negative Conductors act in Opposite Directions.* — Insulate both conductors of the machine, and charge them with electricity by turning the plate. Bring a pith ball suspended by a silk thread in contact with the positive conductor, and it is soon repelled. Take it now to the negative conductor, and it is strongly attracted. Discharge now the pith ball by taking it in the hand, and again bring it in contact with the negative conductor, and it is repelled; but on taking it to the positive conductor it is attracted. We see then that a ball which is repelled by the force on one conductor is attracted by the force on the other. In other words, the forces on the two conductors act in opposite directions.

These opposite electrical forces are called *positive* and *negative* forces.

292. *Both Electrical Forces are always developed together.* — It is found to be impossible to develop one of these forces without at the same time developing both. The positive force always appears upon one of the substances rubbed together, and the negative force always appears upon the other. The force that acts in the same way as that upon the prime conductor of an ordinary electrical machine is called *positive electricity*, and the opposite force is called *negative electricity*. Of course, in order that both the forces should be detected, both of the substances rubbed together must be insulated.

293. *Induction.* — If an insulated copper ball be connected with the prime conductor of the machine, and a small insulated conductor be placed near it (see Figure 211), on developing electricity and examining the condition of the insulated conductor, opposite electrical forces will be found to be developed upon its ends. On the end next the ball, negative force

Fig. 211.



will be found; on the end farthest from the ball, positive force.

This action of a charged body upon a body near it is called *induction.* The insulated conductor is said to be *polarized.*

When an insulated conductor is brought near a charged body, it is first *polarized*, and the nearer it is brought, the higher the polarization rises. If the conductor is so situated that it can discharge its force at the end nearest the polarizing body, it becomes *charged* with the same electric force as the polarizing body; if it discharges from the opposite end, it becomes charged with the force opposite to that on the polarizing body. If the conductor is so situated that it can discharge quite readily at both ends, but more readily at one end than at the other, there will be three steps in the process. It will first become *polarized*, then *charged*, and finally *neutralized.*

If the conductor can discharge quite readily, and with equal readiness at each end, there will be only two steps in the process: it will be first *polarized*, and then *neutralized.*

294. *The Polarization of the Insulated Conductor depends on the Non-Conducting Medium which separates it from the Charged Body.* — Charge a metallic disc, and bring it near the ball of the gold-leaf electroscope; the leaves diverge, owing to the electricity induced upon them. Put a thick cake of shellac between the disc and the ball, and the leaves diverge still more, showing that the polarization has risen higher. The polarization of a body changes whenever a different non-conductor occupies the space between it and the charged body. The polarized condition of a body then depends upon the non-conducting medium which separates it from the charged body.

295. *The Charge on a Solid Insulated Conductor is always on the Surface.* — To an insulated copper ball are care-

fully fitted two hemispherical metallic caps provided with insulating handles. The caps are placed upon the ball, and the whole apparatus is charged. The caps are then removed and examined, and are found to be charged, while not the slightest trace of a charge is found on the ball.

296. *Distribution of the Charge on the Surface.* — It is found by experiment that, when a spherical conductor is charged and placed in the centre of a room, the charge is distributed uniformly over its surface; and that, when an oblong conductor is charged and placed in a similar situation, the charge accumulates at the ends.

297. *The Charge which any Body can receive depends upon its Facilities for carrying on Polarization.* — This fact is illustrated by a simple piece of apparatus. It consists of three cups made to fit closely within one another. The outer and inner ones are of tin; the middle one, which is higher than the others, is of glass. In the centre of the inside tin cup there is an upright glass tube, within which is a brass chain attached to the bottom of the cup, and having a brass ball at the other end. Remove the outside tin cup, place the glass cup on an insulating stand, and bring the brass ball of the inner cup near the prime conductor of the machine. Few sparks will pass, showing that the cup receives but a small charge. Discharge the cup, replace the outside tin cup, connect the latter with one of the conductors of the machine, and bring the ball of the inside cup near the other conductor of the machine. A large number of sparks can now be made to pass, showing that the cup can receive a much larger charge. In the first case polarization has to be carried on through the glass and the air outside, to the nearest conductors; while, in the second case, it is carried on merely through the glass which separates the two coats. Hence there is much less resistance to polarization in the second case; and, as we have seen, the cup receives much the greater charge.

Remove the inner cup by taking hold of the glass tube, and then the glass cup. Very little electricity will be found on the tin cups, but on rubbing the hand over the glass cup we find that cup to be charged.

298. *The Leyden Jar.* — Replace the two metallic cups with tinfoil, and the apparatus just described becomes a *Leyden jar.* This jar is charged by connecting its outer coating with one conductor of an electrical machine, and the inner coating with the other, and developing electricity.

The jar may be discharged by means of the *discharger*, which consists of two bent brass arms connected by a movable joint and having brass balls at their ends. It is fastened at the joint to a glass handle. To discharge the jar, hold the discharger by the glass handle, and bring one ball in contact with the outer coating and the other ball near the knob connected with the inner coating.

299. *The Leyden Battery.* — The amount of charge which a Leyden jar can receive, other things being equal, evidently increases with the size of the coatings. The area of the coatings can be increased, either by making the jar larger, or by connecting together several smaller jars. The latter arrangement constitutes a *Leyden battery.* Like the cells of the voltaic battery, the jars can be connected in two ways : (1.) the outer coating of one may be connected with the inner coating of the next, and so on throughout the series ; or, (2.) the outer coatings may all be connected together, and also the inner coatings. In the first case, the battery is discharged by bringing the inner coating of the first jar in contact with the outer coating of the last , in the second case, by bringing the connected outer coatings in contact with the connected inner coatings. Like the voltaic battery, when the Leyden battery is arranged in the first way, it gives electricity of the greatest intensity ; and, in the second way, electricity of the greatest quantity.

The spark obtained from a powerful Leyden battery can be made to imitate on a small scale all the effects of lightning. It can be made to split tough bits of wood, shiver glass, and the like.

300. *The Effect of Points on a Conductor.* — It is found to be impossible to charge a conductor when a sharp point projects from it, or is held near it. The point conveys away the electric force silently. If the hand is held in front of the point when the electricity is developed, a current of air is distinctly felt setting off from the point. If a lighted taper is held near the point, the flame is blown away from it. The electric force is then evidently carried off by the molecules of the air which form the current, and hence it is called *convective discharge.* Since in a darkened room a star of light is seen upon a point held near a powerful electrical machine while in action, this silent discharge is also called *glow discharge.*

The charge rises so high at the point that the molecules of air just about it are strongly polarized. They then seem to act like little pith balls. The molecules directly in front of the point are first attracted and then repelled; while those just behind are in turn drawn to the point and then driven from it, giving rise to a current of air from the point.

301. *The Electric Wheel.* — As each molecule is repelled from the point, it also repels the point itself, which, if free to move, ought to move as well as the molecules of air. This explains the action of the *electric wheel,* which consists of a number of points all bent round in the same direction, as shown in Figure 212. The wheel is poised so as to turn easily, and when connected with the prime conductor of the machine in action, it rotates rapidly, each point moving backwards.

Fig. 212.

SUMMARY.

When unlike substances are rubbed together, *frictional electricity* is developed. (288.)

Frictional electricity has slight quantity but enormous tension; while voltaic electricity has slight tension but enormous quantity. (289.)

Two opposite electrical forces are developed on the two conductors of the electrical machine; and one cannot be developed without at the same time developing the other. (291, 292.)

A body is *polarized* when it has opposite electrical forces developed on opposite parts; it is *charged* when it has only one electrical force upon it.

A body charged with either electrical force polarizes an insulated conductor near it, *inducing* upon the face nearest itself the opposite electrical force. The polarized condition of such a conductor depends upon the non-conducting medium between the two bodies. (293, 294.)

The charge which a body can receive depends upon the readiness with which it can carry on polarization, as is shown in the case of the Leyden jar. (297, 298.)

The action of points on charged bodies is to convey the charge off silently by *convective discharge.* (300.)

ELECTRICAL MACHINES AND APPLICATIONS OF ELECTRICITY.

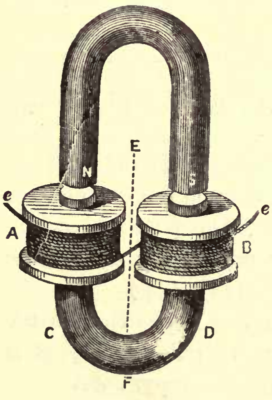
MACHINES FOR DEVELOPING ELECTRICITY.

302. *Magneto-electric Machines.* — The batteries for developing voltaic electricity have already been described.

An instrument for developing electricity by means of magnetism is called a *magneto-electric machine.* In ordinary machines of this kind the electricity is induced by means of a variable magnet: there must, therefore, be some means of developing and destroying magnetism in a piece of soft iron. The iron is placed inside a helix, which serves as a conductor for the current induced. The magnetism may be developed and destroyed by means either of a permanent magnet or of an electric current.

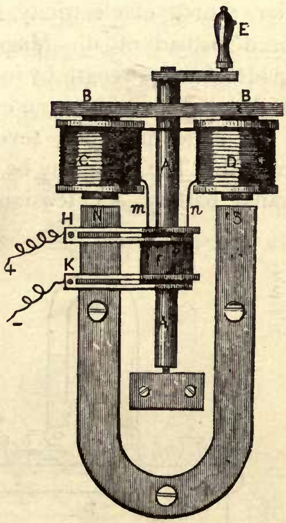
The former method is illustrated by Figure 213. *N S* is a permanent horseshoe magnet. *C D* is a bar of soft iron with coils, *A* and *B*, wound round its ends, and may be viewed as the armature of the magnet. *C D* is capable of rotation round the axis *E F*. So long as *C D* remains at rest, no currents are induced in the coils, for no change takes place in the magnetism induced in it by the action of *N S*. But if the poles of *C D* leave *N S*, the magnetism of the soft iron diminishes as its distance from *N S* increases, and when it stands at right angles to its former position, the magnetism has disappeared. During the first quarter-revolution, therefore, the magnetism of the soft iron diminishes, and an electric current is induced in the coils. During the second quarter-revolution the magnetism of the armature increases till it reaches a maximum when its poles are in a line with those of *N S*. A current also marks this increase, and moves in the same direction as before; for though the magnetism increases instead of diminishing, which of itself would reverse the induced current, the poles of the armature, having changed their position with relation to those of the permanent magnet, have also been reversed, and

Fig. 213.



this double reversal leaves the current to move as before. For the second half-revolution the current also moves in one direction, but opposite to that of the first half-revolution, since the position of the armature is reversed. Thus *in one revolution of a soft iron armature in front of the poles of a permanent magnet, two currents are induced in the coils encircling it, each lasting half a revolution, starting from the line joining the poles.*

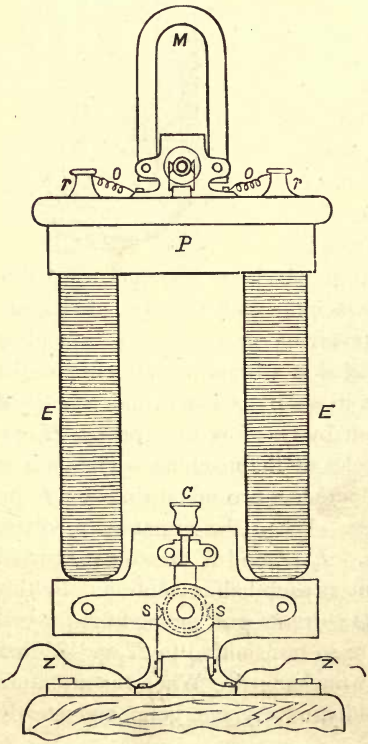
Fig. 214.



The manner in which the armature may be made to rotate, and the current to flow constantly in one direction, is shown in Figure 214, which represents a common form of magneto-electric machine. *N S* is a fixed permanent magnet. *B B* is a soft iron plate, to which are attached two cylinders of soft iron, round which the coils *C* and *D* are wound. *C B B D* is thus the revolving armature, corresponding to *C D* in Figure 213. *A A* is a brass rod attached to the armature, and serving as its axle. *F* is a cylinder fastened to *A*, and is pressed upon by two fork-like springs, *H* and *K*, which are also the poles of the machine. The ends *m* and *n* of the coil are soldered to two metal rings on *F*, insulated from each other. When the armature revolves, *A A* and *F* move with it. *F*, *H*, and *K* are so constructed as to reverse the current at each half-revolution. By this arrangement, the opposite currents proceeding from the coil at each half-revolution are so transmitted to *H* and *K*, that these retain their polarity unchanged. When the armature is made to revolve rapidly, a very energetic and steady current is generated, which has all the properties of the galvanic current. Compared with the galvanic battery, the magneto-electric machine is a readier, steadier, and cleanlier source of electricity, and has come to be extensively used instead of it. Magneto-electric machines may be made of any strength by increasing the number of magnets and the mechanical force employed.

In large machines, several magnetic batteries are employed. The coils may be arranged, like the cells of a galvanic battery, for tension or for quantity. For giving shocks, or for electrolysis, the wire used must be long and fine; for heating platinum wire, thicker and shorter. The electric force increases with the rapidity of rotation.

Fig. 215.

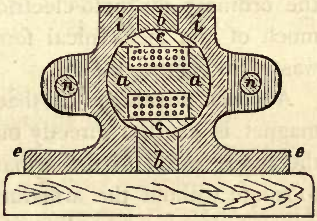


303. *Wilde's Magneto-electric Machine.* — A magneto-electric machine of great power has been recently invented by Mr. Wilde, of Manchester, England. A front view of the machine is shown in Figure 215. *M* is the foremost of a series of sixteen powerful steel magnets of horseshoe form, placed one behind another in a horizontal row. These magnets are fixed be-

low to the *magnet cylinder*, shown on a larger scale in Figure 216. This is made partly of iron, partly of brass. The sides *i i* are of iron, and the brass bars *b b* lie between them. In the centre is a circular hole extending the whole way through. The magnets are firmly fastened to the iron sides *i i*, so that the latter form the poles of the magnetic battery, the brass bars between them insulating them from each other.

A cylindrical armature *a a* of cast iron is made to revolve within the magnet cylinder. Its diameter is a little less than that of the cylindrical hole, so that it can revolve without friction very close to the polar surfaces. It is shown in section in Figure 216. Two rectangular grooves are cut in it, as there represented, and in these about fifty feet of insulated copper wire is wound lengthwise in three coils. The coil thus formed is shut in by wooden packing, *c c*. Two caps of brass are fitted to the ends of the armature, and to these are attached the steel axes of rotation. The rear axis is connected by means of a pulley and belt with the engine which rotates the armature. On the front axis are two metallic pieces, one connected with the armature, and the other insulated from it. One end of the armature coil is connected with the armature, and thus with one of these metallic pieces, and the other end is insulated from the armature and connected with the other piece; so that these metallic pieces are the terminals of the coil. Two steel springs press against these pieces, each spring against one piece during half a rotation. In the position shown in Figure 216, the armature is magnetized, since the parts *a a* are facing the poles of the per-

Fig. 216.



manent magnets. On performing a quarter-revolution, the armature loses its magnetism, since its poles are carried away from the poles of the magnets. After another quarter-revolution, it again becomes magnetic, and so on; so that in one revolution the armature induces two opposite currents in the coil, one in each half-revolution. The springs act in such a way that the current passes through them always in the same direction. The armature is made to revolve some 2,500 times per minute, sending 5,000 waves or currents of electricity to the wires *o o*.

One advantage of the position of the armature in this machine is that its motion is not resisted by the air. In the ordinary magneto-electric machines (see Figure 214) much of the mechanical force applied to the rotation is wasted in beating the air.

Another advantage is that the inductive action of the magnet is exerted directly on the coil, as well as through the intervention of the armature. If the coil were made to rotate without the armature, currents would be induced in it of the same kind as that induced by the armature, though of feebler intensity; and these currents would be strongest when the coil was moving through the line joining the poles, and weakest when it was at right angles to that position. The currents induced by the armature are strongest when those just mentioned are weakest, and weakest when those are strongest; so that armature and coil combine to make the current uniform.

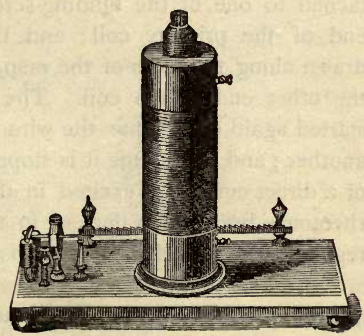
But the chief peculiarity and merit of Wilde's machine is that the current got from the magneto-electric apparatus is not directly made use of, but is employed to magnetize an electro-magnet, *E E* (Figure 215), some hundreds of times more powerful than the magnetic battery originally employed, and this electro-magnet is made to induce another and proportionally more powerful current by means of a second rotating armature. The upper and lower machine are in action precisely alike; only the upper magnet is a permanent magnet, and the lower one an electro-magnet. We have the same magnet cylinder, the same armature, springs, and poles. This armature is made to rotate some 1,800 times per minute.

A machine intended for a three-horse power steam-engine, and worked with that power, will consume carbon sticks three eighths of an inch square, and evolve a light of surpassing brilliancy. With a machine consuming carbons half an inch square, the light is of sufficient intensity to cast shadows from the flames of street-lamps a quarter of a mile off. The same light, at two feet from the reflector, darkened photographic paper as much in twenty seconds as the direct rays of the sun at noon in one minute.

Wilde's machine enables us to convert any amount of mechanical force into electricity by increasing the size of the electro-magnet, or by using a second electro-magnet induced by the first; so that *a magnet indefinitely weak can be made to induce a current or a magnet of indefinite strength.* The size and weight of the apparatus are also small.

304. *Induction Coils.* — When the magnetism is developed and destroyed by means of a current, the soft iron must be placed inside a coil through which the current is sent. This is called the *primary coil*, and must be placed inside another coil, called the *secondary coil*, which serves as a conductor of the induced electricity. Such a machine is commonly called an

Fig. 217.



induction coil. In the one shown in Figure 217, the primary coil is of coarse wire wound with wool, and is attached to the wooden base of the instrument. The secondary coil is of finer silk-wound wire, much longer than the primary wire. Within the primary coil is a bundle of iron wires, which are sufficiently insulated by the rust that gathers on them. The developing of magnetism in these wires is the chief aim of the primary coil, and, as a strong current is necessary for that purpose, coarse wire is used in that coil. In the secondary coil, the tension of the induced current alone is aimed at, and fine wire is used, so that as many turns as possible may be brought within the influence of the primary coil and its core; for it is found that *the tension of the induced current is proportional to the strength of the primary current, and to the square of the resistance in the secondary coil.*

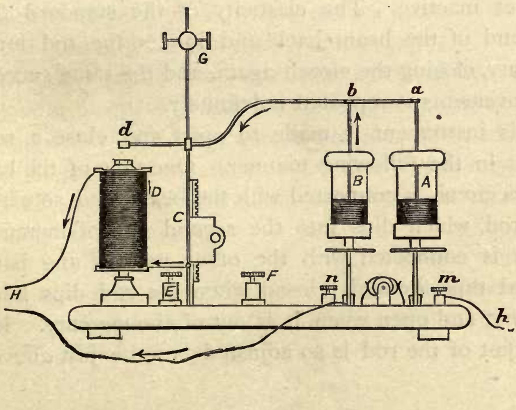
In order, however, to obtain the greatest effect from the secondary coil, it is necessary to have some means of rapidly completing and breaking the primary current. This is effected in the instrument under consideration, either by means of the rasp seen behind the coils, or by the self-acting *rheotome* (that is, *current-cutter*) at the left hand. When the former is used, one of the battery wires is attached to one of the binding-screws, and thereby to one end of the primary coil; and the other battery wire is drawn along the teeth of the rasp, which is connected with the other end of the coil. The current is stopped and started again every time the wire passes from one tooth to another; and every time it is stopped or started, an inverse or a direct current is excited in the secondary wire. The rheotome breaks the current in the same way, but more regularly and rapidly. When it is used, both battery wires are attached to the binding-screws, bringing the rheotome and the primary coil into the circuit.

305. *The Inductorium, or Ruhmkorff's Induction Coil.* — The essential parts of this apparatus, like those of the one described in the last section, are a primary coil, with its core of iron wire, and a secondary coil outside the primary and insulated from it. The primary coil is connected with a galvanic battery, and a rheotome is used to interrupt the current, as already explained.

A Ruhmkorff's coil of moderate size readily yields sparks of from four to five inches, with a battery of six Bunsen's cells. The power of the induced current to deflect the needle of the galvanometer, and to effect electrolysis, is very insignificant. This shows that it is very much inferior to the inducing current in quantity, however much it may be superior in tension. The physiological effect, however, is tremendous, and the experimenter must take care not to allow any part of his body to form the medium of communication between the poles, as the shock might be dangerous, if not fatal.

306. *Foucault's Self-acting Rheotome.* — The best rheotome for use with the inductorium is Foucault's. This instrument is shown in Figure 218, and illustrates one of

Fig. 218.



the many applications of the electric force to doing mechanical work. It consists of a beam, *a d*, supported by a standard *C G*, which acts as a spring. At one end of the beam there is a keeper of soft iron; at the other end, two iron rods, which plunge into cups *A*, *B*, partially filled with mercury. Under the iron keeper is an electro-magnet, *D*. One end of the wire of the helix of this magnet connects with one pole of a Bunsen's cell. The other pole of this cell is connected with the mercury cup, *B*. The other end of the wire of the helix is connected with the beam by means of the standard; so that the circuit of the Bunsen's cell is closed when the iron rod dips into the mercury, and is open when it is out of the mercury. It is best to cover the mercury with alcohol, which is a non-conductor.

When the rheotome is to be worked, the iron rod is so adjusted that its end is just above the surface of the mercury. That end of the beam is then depressed by the hand so as to bring the rod into the mercury. This closes the circuit, and renders the electro-magnet active, and the keeper at the end of the beam is drawn down upon it. This carries the other end of the beam up and the rod out of the mercury, opens the circuit, and renders the electro-magnet inactive. The elasticity of the standard throws this end of the beam back and lowers the rod into the mercury, closing the circuit again, and the same succession of movements is repeated indefinitely.

This instrument is made to open and close a second circuit in the following manner. One pole of the battery of this circuit is connected with the beam, and so with the iron rod, which dips into the second cup of mercury, *A*, which is connected with the other pole of the battery; so that this circuit is closed when the rod dips into the mercury, and open when it is out of the mercury. But if the point of the rod is so adjusted as to be just above the surface of the mercury, it is drawn out of it every time that the keeper is drawn down to the electro-magnet, and is plunged into it every time that the keeper is thrown back by the spring.

307. *Geissler's Tubes.* — A variety of forms of apparatus are used for showing the electric light in rarefied air and in other gases.* *Geissler's tubes*, so called from the inventor, are combinations of bulbs and tubes, filled with rarefied gases and liquids, and then sealed air-tight, so as to be ready for use at any time. One of them is shown in

Fig. 219.

Figure 219. When the current is sent through these tubes, they exhibit lights of various tints according to the gases contained in them.

SUMMARY.

In ordinary magneto-electrical machines electricity is induced by developing and destroying magnetism in soft iron placed inside a helix. This may be done by using a permanent magnet, or, as in the various forms of *induction coils*, by means of the current. (302, 304, 305.)

In Wilde's machine, the electricity obtained by means of permanent magnets is made to develop much more powerful magnetism in a large electro-magnet, which in turn is made to develop electricity. In this way a magnet indefinitely weak may be made to develop a current indefinitely strong. (303.)

* All the experiments with the electric light usually performed by means of Frictional Electricity can be better performed with the *Inductorium*. See Appendix, Note 8.

APPLICATIONS OF ELECTRICITY.

308. *Electrotyping.* — When the solution of cupric sulphate is decomposed slowly, the copper is deposited on the cathode in a coherent mass, which may be stripped off when it has become sufficiently thick. The sheet of copper stripped off is found to present a perfect reverse image of the face of the cathode, the faintest lines being copied with perfect distinctness. If this reverse image be now made the cathode, and another sheet of copper be deposited upon it, an exact copy of the original electrode is obtained. Any conducting substance, of whatever size and shape, may be made a cathode by simply connecting it with the negative pole of the battery. Hence coins, medals, and engraved plates may be copied with perfect accuracy, and with but slight trouble and expense.

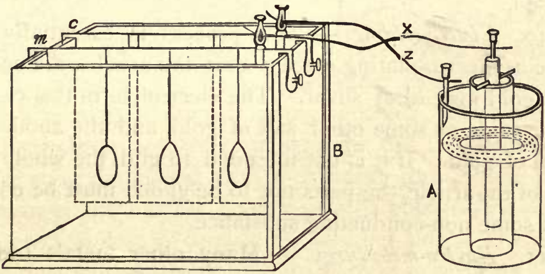
This process of copying by means of electricity is called *electrotyping.*

The face of a medal may be copied by making it the cathode and depositing a sheet of copper upon it, and then depositing another sheet of copper upon this sheet after it has been separated from the medal. In practice, however, a mould of the thing to be copied is first taken in some soft substance, such as plaster, gutta-percha, or wax, and this mould is made the cathode. If the mould is made of non-conducting material, as is usually the case, its surface must be covered with some conducting substance, as powdered graphite. The mould may be covered by means of a hair brush with a film of graphite sufficient to make it a conductor, without obliterating the finest lines.

One of the chief uses of electrotyping is in copying printer's type after it has been set up, and in copying wood engravings. An impression is taken of the type or of the engraving in wax. This wax is then brushed over with powdered graphite, and made the cathode; the electrolyte is cupric sulphate, and the anode a piece of copper.

A large bath is used (see Figure 220), so that several

Fig. 220.



pieces may be electrotyped at the same time. These are all hung by wires to a metallic rod which is connected with the negative pole of the battery. Upon another metallic rod pieces of copper are hung opposite to the pieces to be copied.

The electric current is sometimes generated in the bath itself. The object to be coated serves as one of the plates of the battery, and a piece of zinc as the other, the wire connecting the two being coated with insulating varnish.

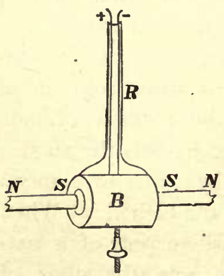
309. *Electro-plating.* — This is the art of coating the baser metals with silver by the electric current. Articles to be electro-plated are generally made of brass, bronze, copper, or nickel silver, this last being the best material.

The bath is a large trough of earthen-ware or other non-conducting substance. It contains a weak solution of argentic cyanide (cyanide of silver) and potassic cyanide (cyanide of potassium). A plate of silver forms the anode; and the articles to be plated, hung by wires to a metal rod lying across the trough, constitute the cathode. When the former is connected with the positive pole of a battery, and the latter with the negative pole, the silver of the cyanide begins to deposit itself on the suspended articles, and the cyanogen, set free at the plate, dissolves it, forming argentic cyanide. The thickness of the plating depends on the length of time the articles are immersed.

310. *Electro-gilding.* — This process is essentially the same as electro-plating, except that the articles are coated with gold instead of silver. The electrolyte in this case is the cyanide or some other salt of gold, and the anode is a lump of gold. If it is not intended to gild the whole surface of the article, the parts not to be gilded must be coated with some non-conducting substance.

311. *Electro-metallurgy.* — Many other metals besides copper, silver and gold may be deposited by electrolysis. The art of depositing, by electro-chemical action, a metal on any surface prepared to receive it, is called *electro-metallurgy.* All processes of the kind may be classified in two divisions, one of which is illustrated by electrotyping, and the other by electro-plating. The former includes all those cases in which the coating of metal is to be removed from the surface on which it is deposited ; and the latter all cases where the coating remains permanently fixed. Gold, platinum, silver, copper, zinc, tin, lead, cobalt, and nickel can be deposited by electrolysis.

Fig. 221.



312. *Electric Clocks.* — The electric force has also been used to regulate the movements of clocks, called *copying clocks.* They are of the usual construction, except that the pendulum balls are hollow coils of copper wire, so that they become magnetic when a current is sent through them. In Figure 221, *R* represents a part of the rod, and *B* the ball, of such a pendulum. Permanent magnets,

NS and *SN*, are fastened against the sides of the clock-case opposite the ends of the coil *B*, with like poles towards the coil. The hollow of the coil, as it swings, can pass a little way up the length of each magnet. If the south poles of the magnets are turned towards the coil, as in the figure, and a current is sent through the wire, one end of the coil becomes a north pole, which is attracted by the magnet near it, and the other end a south pole, which is repelled by the magnet near it. This attraction and repulsion both tend to send the coil in one direction. If, now, at the instant that *B* is drawn to one side, the direction of the current is changed, the poles of the coil are reversed, and it is carried to the other side. The pendulum thus vibrates every time the current is reversed. This is done by means of a standard or regulating clock. Every time the pendulum of this clock vibrates, the direction of the current is reversed; so that the pendulums of all the copying clocks vibrate exactly at the same rate as the pendulum of the regulating clock. In this way, by means of one accurate clock, any number of copying clocks, of the most ordinary construction, can be made to keep accurate time.

Fig. 222.

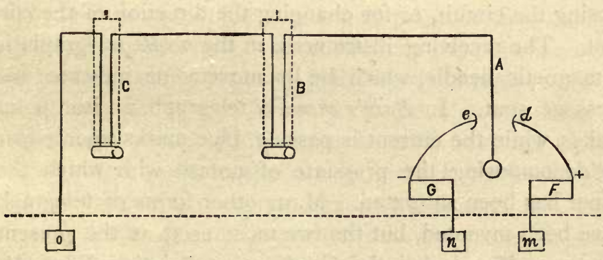


Figure 222 shows one of the ways in which the pendulum, *A*, of the regulating clock can change the direction of the current. The spring *e* is connected with the negative pole of the battery *G*, and the spring *d* with the positive pole of the battery *F*. The other poles of these batteries are connected with the plates *m* and *n*, buried in the earth. *B* and *C* are the pendulums of the copying clocks. When the regulating pendulum touches the spring *d*, the current flows through the wire from *A* to *B* and *C*; when it touches the spring *e*, the current flows first through the earth from *n* to *o*, and then through the wire from *C* to *A*. The permanent magnets connected with the pendulums *B* and *C* are not represented in the diagram.

313. *The Electric Telegraph.* — Since the electric current passes with comparatively little resistance through thick conductors of almost any length, it is now much used in transmitting signals between distant stations. An instrument for sending such signals is called a *telegraph*. The word literally means *writing at a distance*.

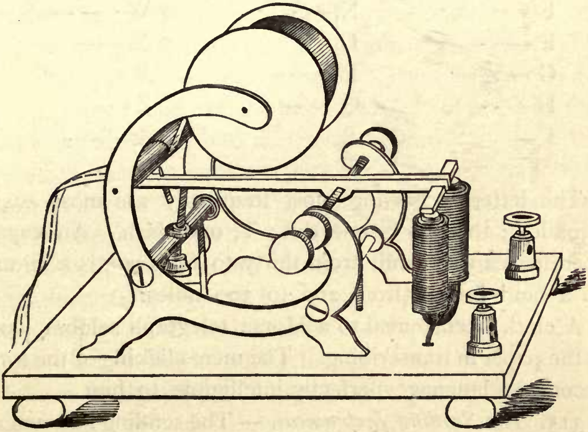
Four things are essential in every kind of electric telegraph: (1.) a battery for generating the electricity; (2.) wires for conducting the electricity; (3.) an instrument for sending the message; and (4.) an instrument for receiving the message.

The battery used is, in almost all cases, a voltaic battery. The sending instrument is merely a *key* for opening and closing the circuit, or for changing the direction of the current. The receiving instrument, in the *needle* telegraph, is a magnetic needle, which by its movements indicates the message sent. In *Bain's chemical* telegraph, an iron point makes, while the current is passing, blue marks upon paper by decomposing the prussiate of potash with which the paper has been saturated. Many other forms of telegraph have been invented, but the two most used at the present time are *Morse's* and the *Combination Printing Telegraph.*

314. *Morse's Telegraph.* — This telegraph depends on the power of the current to develop magnetism in soft iron, and hence is an *electro-magnetic* telegraph.

The essential parts of the receiving instrument are shown in Figure 223. One of the screw-cups at the right is con-

Fig. 223.



nected with the line wire from the distant station, and the other with the earth. The current traverses the coils of the electro-magnet, and draws down the keeper and the arm of the lever to which it is attached. The other end of the lever is raised, pressing a steel point, or style, against a strip of paper, which is unrolled from the bobbin above, and moved steadily along by clock-work not represented in the figure. When the current from the distant station is broken, the shorter arm of the lever is released by the electro-magnet, the longer arm falls back by its weight, and the style ceases to press against the paper. The kind of mark made upon the paper depends upon the time the style remains elevated. If it is raised for a moment only, a dot is made ; if for a longer time, a dash. The alphabet used is made up by the combination of dots and dashes. The following is the usual Morse alphabet : —

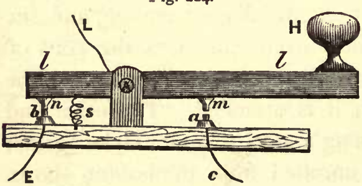
A — -	J — - — -	S - - -
B — - - -	K — - —	T —
C - - -	L ——	U - - —
D — - -	M — —	V - - - —
E -	N — -	W - — —
F - — -	O - -	X - — - -
G — — -	P - - - - -	Y - - - -
H - - - -	Q - - — -	Z - - - -
I - -	R - - -	& - - - -

The letters occurring most frequently are most easily signalled; thus, E is one dot; T, one dash. An expert operator can transmit from thirty to forty words a minute on a land line of from 200 to 300 miles.

A clerk accustomed to a Morse telegraph seldom looks at the paper in transcribing. The mere clicking of the lever becomes a language perfectly intelligible to him.

315. *The Sending Instrument.* — The sending instrument, or *transmitting key*, is shown in Figure 224. A brass lever, *l l*, moves on the axis *A*. It has two projections of platinum, *m* and *n*, on its lower side. These strike against pieces of platinum *b* and *a*, the first of which is connected with the earth-wire *E*; the second, by the wire *c*, with one of the poles of the sending battery. When the lever is left to itself, *n* and *b* are in contact under the force of the spring *S*. When the hand presses on the ebony handle *H*, contact is broken at *n* and *b*, and established at *m* and *a*. Besides the wires *E* and *c* already mentioned, the line wire *L*, from the distant station, is connected with the lever, through its axis, *A*. When the key is in the receiving position (as shown in the figure), the current from the

Fig. 224.



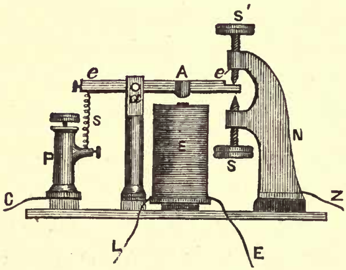
sending station takes the route, *L*, *A*, *l*, *n*, *b*, *E*, the recording instrument, then to earth. When *H* is pressed down, the key is in the sending position, and transmits the battery current by *c*, *a*, *m*, *A*, *L*, to the distant station.

316. *The Earth.* — One wire is quite sufficient to connect two telegraph stations, if its terminations be formed by two large plates sunk in the earth. The plates are generally of copper, and should have a surface of not less than twenty square feet; and they must be buried so deep that the earth about them never gets dry. The gas and water pipes in a town make an excellent *earth*, or earth-connection. When the *earths* are good, the current passes through the earth between the two stations, no matter what may be the nature of the region it has to pass, — plain or mountain, sea or land. The resistance of the earth to the current, compared with that of a long line, is next to nothing. The earth serves the purpose, not only of a second wire, but of one so thick that its resistance may be left out of account. In conducting power, for equal dimensions, the earth stands much inferior to the wire; but then its thickness, so to speak, is indefinitely greater, and hence its conducting power, on the whole, is superior.

317. *The Relay.* — It is only on short circuits, generally of less than fifty miles, that the receiving instrument is worked directly by the line current. On long circuits, direct working could only be accomplished by an enormous sending battery. The loss by leakage on the way is very considerable, so that a current strong at starting becomes very weak before it reaches the station to which it is sent. Besides, the leakage is the greater, the greater the number of cells employed, or the greater the tension of the battery. It is found a much better arrangement to work the receiving instrument by a local current, and to include in the line circuit a very delicate instrument, which has only to make or break the local circuit. Such an instru-

ment is called a *relay*, and is shown in Figure 225. The electro-magnet, *E*, of the relay is included in the line circuit, instead of the electro-magnet of the receiving instrument.

Fig. 225.



The coil is long, and of very fine wire; and a very faint current is sufficient to develop magnetism in the core. The keeper, *A*, of the relay is attached to a lever, *e e'*, turning on the axis *a*. When a current is sent through the coil, the lever is drawn down, and the end *e'* rests on the screw *S*. When there is no current, the elasticity of the spring *s* brings it back against the screw *S'*. The pillars *N* and *P* are connected with the poles of the local battery. The metal spring *s* places the lever *e e'* in connection with *P*. The screw *S* and the end *e'* of the lever, then, are virtually the poles of the battery. When these are in contact, the local current flows, and it stops when *e'* is brought back against the insulated screw *S'*. The receiving instrument is included in the local circuit. When a current comes from the sending station, the keeper *A* is attracted, *e'* falls on *S*, the local circuit is closed, and the receiving instrument begins to print. When the current ceases, *e'* returns to *S'*, and the style of the receiving instrument is withdrawn from the paper. The effect is thus the same as if the line current printed, and not the local current. By this means, a current too weak to work the receiving instrument can complete the local circuit and print legibly.

318. *The Combination Printing Telegraph.* — The Morse recording instrument, as we have seen, writes by means of dots and dashes. An instrument has been invented by Mr. Royal E. House, a native of Vermont, which records

the message in plain Roman letters. This telegraph is known as House's Printing Telegraph, and was patented in 1848. It has been found to work well, and has been used on many lines.

In 1855, Mr. David E. Hughes of Kentucky, after ten years of persevering labor, produced a printing telegraph on a new principle, simpler in construction and capable of working upon long circuits. In this telegraph each electric impulse sent over the wire prints a letter, while the House instrument requires on an average seven impulses for each letter, and the Morse an average of three and a half impulses.

Both these printing telegraphs have now been in great measure superseded by the Combination Telegraph devised by Mr. Phelps of Troy, N.Y. This instrument, as its name indicates, is a combination of the principles of the two preceding telegraphs, with certain improvements, originated by Mr. Phelps.

The sending instrument somewhat resembles a piano in outward appearance. On the key-board are twenty-eight keys, upon which are printed the twenty-six letters of the alphabet, a dot, and a dash. Near the key-board is a brass cylinder. On each key there is a peg, and in the cylinder there are twenty-eight cavities, one for the peg of each key, so arranged that each peg can enter its own cavity, and no other. The cavities are arranged spirally around the cylinder, so that each cavity is $\frac{1}{28}$ of the circumference of the cylinder behind the preceding one. The cavity is so formed that the peg of the key, on entering it, is carried a little to the left, and thus completes the circuit. If all the keys were depressed at once, the circuit would be closed twenty-eight times at equal intervals during one rotation of the cylinder. If a key at the beginning of the alphabet, and another at the middle, were depressed and kept depressed during one rotation, the circuit would be closed twice, and the interval between the closings would be that of half a rotation. By means of this instrument the circuit can be closed with great precision at fixed intervals.

At the receiving station there is a small disc, called the *type-wheel*, on the edge of which are types of the twenty-six letters and the dot and dash, arranged at equal intervals. By the side of the type-wheel is a little press just large enough to take off one letter from the type-wheel. This press is forced against the type-wheel by machinery. When this machinery is at rest, the press is thrown back from the type-wheel by a spring. A strip of paper is carried along between the type-wheel and the press at such a rate that it advances the width of a letter every time the press is pushed against the wheel.

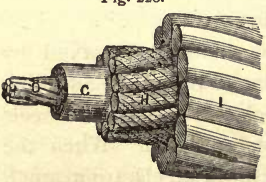
The type-wheel and press are moved by clock-work, as is also the printing cylinder at the sending station. The clock-work at each station is regulated by the vibrations of springs which are capable of vibrating the same number of times a minute; so that the printing cylinder and the type-wheel move at exactly the same rate. The two instruments are so set that the letter *A* on the type-wheel is opposite the press at the same instant that the cavity in the printing-cylinder corresponding to that letter is under the peg of its key. If the key were depressed at this instant, the circuit would be closed, an electric impulse would be transmitted, and, in passing through the coil of the electro-magnet at the receiving station, would render it active and cause it to draw down its keeper. To this keeper is attached a *detent*, or catch, which arrests the motion of the machinery that works the press. When the keeper is drawn down by the magnet, this detent is withdrawn, the press is driven forward, and the letter opposite is printed on the paper. When the circuit is again opened, the keeper is thrown back by means of a spring, the detent replaced, and the press removed from the type-wheel by the spring arranged for that purpose. Since both the type-wheel and the cylinder rotate at the same rate, it is evident that, when the peg of any key enters its cavity, the letter of that key will be printed at the receiving station. Every time the circuit is closed, — that is, every time a key is depressed, — the detent is withdrawn from the wheel that moves the press, and a letter is printed on the paper. The type-wheel rotates at the rate of about one hundred and twenty times a minute. The ordinary speed of this instrument is two thousand words an hour, which is about twice as fast as the Morse can work.

319. *The Telegraphic Fire-Alarm.* — The electric telegraph is now extensively used for indicating the locality of fires in cities. In various parts of the city are small iron boxes called *signal-boxes.* They are all numbered, and connected with a central station by means of wires. By turning a crank which is found inside the signal-box, the circuit is opened and closed in such a way as to telegraph to the central station the number of the box. When, therefore, a fire occurs in the neighborhood of any box, the box is opened, the crank turned, and the number of the box telegraphed to the central station. This station is also connected by wire circuits with several bells in different parts of the city, and the operator, by means of the electric force, rings on these bells the number of the box near which the fire is, so that the firemen know at once almost the exact locality to which they must go.

The hammers which strike the bells are worked by weights, the machinery being similar to that of the striking apparatus in an ordinary turret-clock. The train of wheels is kept from moving by a detent, or catch. When the current passes, it develops magnetism in an electro-magnet, which attracts a keeper in front of it. This keeper supports a small lever poised nearly vertically, and weighted with a little ball near its upper end. This lever is tripped by the withdrawal of the keeper, and in falling acquires sufficient force to strike up the detent. The machinery is thus set in motion, and the hammer strikes the bell. A single blow of the hammer follows each electrical impulse, and the motion of the machinery raises the lever again to its place, and poises it on the keeper ready to be tripped for another blow. If the number of the box is ten or less, it is indicated by a corresponding number of strokes on the bell. If above ten, the digits of the number are indicated by striking the numbers corresponding to them, with a short pause between. Thus, to strike the number 25, two blows would be given, and then after a pause five more. Numbers containing ciphers, and those made up of figures repeated, as 22, 33, etc., are not used for the signal-boxes.

320. *Submarine Lines.* — A submarine line is made by a cable. The core of the cable consists of one wire, or more commonly a strand of several wires, of copper. This is generally covered with a compound of gutta-percha and resinous substances, which fills the interstices between the wires. It is then included in one or more coatings of gutta-percha, then in a layer of tarred yarn, and finally in a sheathing of iron wire, laid on spirally, to give the cable sufficient strength to withstand the strain of paying out, or that to which it may be subjected from the inequalities of the ocean bed. Figure 226 shows the construction (full size) of the Malta and Alexandria cable, 1330 nautical miles long, and one of the best in operation. *O* is a strand of seven copper wires, laid in a compound of gutta-percha and resins ; *C*, three layers of gutta-percha, with the same compound between them ; *H*, tarred yarn ; and *I*, the eighteen wires of the sheathing. The di-

Fig. 226.



ameter is .85 of an inch. Near the shore, where it is more exposed to injury, the sheathing is made much stronger.

321. *Electricity as a Source of Mechanical Power.* — A great variety of electro-magnetic machines have been constructed with a view to applying electric force to the work now done by steam. They all depend on the power of an electro-magnet to acquire or to lose its magnetism on the passage or the interruption of the current; or to reverse its poles when the direction of the current is changed.

Electro-magnetic engines have never yet been constructed of above eight or ten horse-power, though there is apparently nothing to limit them to this low power. The great obstacle to the success of these engines is the expense of generating the electricity to run them. It costs some forty or fifty times as much to generate electric force as to generate the same amount of steam force. Yet, for certain kinds of work, where rapid motion and comparatively little force are required, electric engines have been found to answer better than small steam-engines.

322. *Electric Lamps.* — Various arrangements have been invented for giving steadiness to the electric light by keeping the carbon points within such a distance of each other that the current can pass between them. Foucault, aided by Duboscq, was the first (1849) to construct an electric lamp of this kind. In it, by means of an electro-magnet and of clock-work, the points are made to travel towards each other at rates corresponding to those of their combustion, the positive pole moving faster than the negative.

The electric lamp has not yet been used successfully for lighting streets. The light may be kept up for hours, but it is not perfectly steady, and the apparatus cannot be safely left without an attendant. It has, however, been used with excellent effect where a limited space had to be lighted for a few nights, as in building bridges. It has also been used with success for light-houses, in England and

France. The power of the electric light to penetrate fogs is found to be far superior to that of the usual oil light.

SUMMARY.

Electro-metallurgy is the art of depositing a metal by electrolysis upon a surface prepared to receive it. In electrotyping the metal deposited is afterwards removed; in electro-plating and gilding it is made to adhere permanently to the surface. (308 – 311.)

The electric force has been used for regulating the motion of clocks. (312.)

Morse's telegraph depends on the power of the current to develop magnetism. (314.)

The Combination Printing Telegraph and the Electric Fire-alarm are other important forms of the electro-magnetic telegraph. (318 – 319.)

CONCLUSION.

We have now become somewhat acquainted with that peculiar mode of molecular motion which we denominate *Electricity*. We have seen that it may be developed by chemical action, magnetism, heat, and friction; and that it has power to decompose chemical compounds, and to develop magnetism, heat, and mechanical motion. We have also seen how extensively this force has come to be applied to the arts, in electrotyping, electro-plating, telegraphy, and illumination.

This mysterious force, which we can generate on a small scale by the above methods, is developed on an enormous scale in nature by processes of which we know little or nothing. The sparks of our most powerful electrical machines, and the most brilliant discharge which we can obtain through a vacuum tube, are but miniature representations of the lightning and the aurora.

APPENDIX.

APPENDIX.

PHYSICS OF THE ATMOSPHERE.

TEMPERATURE OF THE ATMOSPHERE.

1. *Composition of the Atmosphere.* — The atmosphere is a gaseous envelope surrounding the earth to the depth of about fifty miles. It is composed mainly of a mixture of nitrogen and oxygen, in the proportion of 79.1 parts of the former to 20.9 of the latter. It contains also a little carbonic acid and a variable amount of watery vapor.

2. *How the Air is Heated.* — The air receives its heat directly or indirectly from the sun. A part of the solar rays are *absorbed* in passing through the atmosphere. It thus becomes warmed *directly* by *solar radiation.* A part of the rays fall upon the surface of the earth, which absorbs them, and thus becomes heated. This heat is then radiated back again, and is absorbed by the air, which thus becomes heated by *terrestrial radiation.*

Owing to the greater specific heat of water, the sea becomes less heated during the day than the land does. Again, it is a poorer radiator than the land. Hence, the terrestrial radiation from the land is much greater than from the sea.

The watery vapor in the air plays an important part in this heating process ; for, while it allows the luminous rays of the sun to pass readily through it on their way to the earth, it will not allow them to pass back again when they are radiated from the earth as obscure heat. The sunbeams are, so to speak, caught in a trap from which they cannot escape.

This is the main reason why it is warmer at the base of a mountain than at its top, where the solar radiations are more powerful. In the upper regions of the atmosphere there is less watery vapor to absorb the terrestrial radiations.

3. *The Daily Variation of Temperature.* — The temperature is found to be greatest, not at noon, when the solar radiations are most intense, but two or three hours later ; and least, not at midnight, but an hour or two before sunrise. During the forenoon, the earth receives more heat than it radiates. In the afternoon it begins to receive less heat, but for two or three hours it still receives more than it radiates, so that it grows hotter and gives out more heat than at noon. During the night, it receives no heat from the sun, and gives out less and less till about an hour before sunrise, when the heat it receives from the returning sun again equals what it radiates.

4. *The Distribution of Temperature in the Atmosphere.* — The highest temperature of the earth is found to be in an irregular belt lying within the tropics. The warm belt is continually shifting its position, passing northward with the sun until midsummer, and then southward again until midwinter.

From the warm belt, the temperature diminishes towards the poles. In the southern hemisphere, which is nearly all water, it shades off gradually and regularly ; in the northern, where there are large bodies of land, the changes are quite irregular. In the summer the atmosphere over the continents becomes much hotter than over the ocean, owing to the greater radiation from the land ; while in the winter the air over the continents is much colder than over the ocean, since the land has cooled down faster than the sea.

The distribution of heat is further modified by the oceanic currents and the prevailing winds. The Gulf Stream and the southwesterly winds keep the temperature of western Europe much above that of the eastern coast of America in the same latitude. For a similar reason, the western coast of America is warmer than the eastern coast of Asia.

ATMOSPHERIC PRESSURE.

5. *The Daily Variation of Atmospheric Pressure.* — The observations of the barometer show two *maxima* and two *minima* of atmospheric pressure during the day: the former occurring from nine to eleven A. M., and from nine to eleven P. M. ; and the latter from three to five A. M., and from three to five P. M.

These variations are much more marked in tropical regions than elsewhere. As the air in the hemisphere under the sun's rays becomes heated, it expands upwards and flows over upon the other hemisphere where the air is colder and denser. There is thus sweeping round the globe, from day to day, a wave of heat, from whose crest the air is continually flowing towards the region of greatest cold. Again, the variation in the elastic force of the watery vapor in the atmosphere tends to produce two maxima and two minima of pressure each day. One maximum occurs at about ten A. M., when the evaporation is most rapid, and the other a little before sunset, when there is the greatest amount of watery vapor in the air. One minimum occurs at about ten P. M., when the dew is falling fastest, and the other a little before sunrise, when there is the least amount of watery vapor in the air. The effect of these, combined with that of the heat-wave, gives the two daily maxima and minima first mentioned.

6. *The Distribution of Atmospheric Pressure.* — In general there is an irregular belt of low pressure within the tropics, bounded on each side by a broad belt of high pressure. North and south of these are other belts of low pressure, while about each pole there is probably a region of high pressure. The belts south of the equator are much more uniform and regular than those north of the equator; as may be seen by reference to Map I. (at the end of the book) on which the blue lines represent pressures below thirty inches, and the red lines thirty inches and above.

In winter (as shown in Map II.), the north polar region of low pressure has two centres of minimum pressure; one in the northern Atlantic near Iceland, and the other in the northern Pacific. At the same time there is a broad belt of high pressure stretching across Asia and North America, with a centre of maximum pressure on each continent.

In summer (as shown in Map III.), there are centres of high pressure in the middle of the northern Atlantic and Pacific; and a broad band of low pressure stretching across North America and Asia, with a centre of minimum pressure on each continent.

There are two things which tend to diminish the atmospheric pressure; high temperature, and great humidity. High temperature causes the air to expand, rise, and flow away to colder regions. Great humidity diminishes the density of the air. Humid air therefore rises, but, in rising, it becomes cooled, and a part of its moisture is precipitated as rain. In this condensation a large amount of heat is given out, which again raises the temperature of the air and causes it to expand still more.

Now in the tropics there is an excess of both heat and moisture. The air therefore rises and flows over towards the north and south, giving rise to the belt of low pressure bounded by belts of high pressure.

Again, in the regions north and south of these belts of low pressure, the air is found to be highly charged with moisture which is brought thither by the prevailing winds, and continually precipitated in rain. Hence, in this region also, the air rises and flows over towards the north and south, producing a region of high pressure towards the poles and increasing the pressure in the belts towards the equator.

The irregularity in the belts of pressure in the northern hemisphere is due to the modifying influence of the continents. In the summer, both North America and Asia become excessively heated, while the adjacent seas are comparatively cool. Hence the air pours over from the land to the sea, giving rise to low pressure on the continents and high pressure on the oceans. The more completely the sea is shut in by the heated land, as in the northern Atlantic, the greater the atmospheric pressure upon it. It is also this excessive heat of the northern continents in summer which causes the great pressure upon the southern hemisphere at the same season. (See Map III.)

In winter the conditions are reversed. The land becomes excessively cold, and the air over it dense and contracted. The warmer air from the sea now pours over upon the land, causing the high pressure in North America and Asia, and the low pressure in the northern Atlantic and Pacific. (See Map II.)

WINDS.

7. *Cause of Winds.* — Winds are currents of air, and are directly caused by atmospheric pressure. If two neighboring regions come to be of very unequal temperature, the lighter air of the warmer region will rise and flow over to the colder region,

while the heavier air of the colder region will flow in below to supply its place. Thus we always have a surface wind blowing from a region of lower temperature and high pressure towards one of higher temperature and low pressure, and an upper wind blowing in the opposite direction. We have an illustration of this in the wind which always sets in from every direction towards a large fire. We have another in the *land* and *sea breezes*. On the sea-coast a breeze sets in from the sea in the morning. At first a mere breathing, it gradually rises to a stiff breeze in the heat of the day, and again sinks to a calm towards evening. Soon after, a breeze springs up from the land, and blows strongly seaward during the night, dying away towards morning, when the sea-breeze begins once more. These breezes are especially marked in tropical regions, where the difference of temperature on land and sea is greatest.

8. *Trade-Winds.* — While the air above is flowing north and south from the tropical belt of low pressure, a surface wind will set in from the region of high pressure to supply its place. Were the earth at rest, these surface winds would blow directly from the north and south towards the equator. But the earth is rotating from west to east, and objects on the surface at the equator are carried round towards the east at the rate of about 17 miles a minute. But as we go away from the equator, this velocity diminishes, so that in latitude 60° it is only 8½ miles a minute, and at the poles it is nothing. The wind, then, blowing towards the equator, is continually coming to places which have a greater velocity eastward than itself, and therefore lags behind and appears to move westward. This, combined with its motion towards the equator, makes the surface wind north of the equator a *northeast* wind, and the one south of the equator a *southeast* wind. These winds blow with great steadiness and constancy, and from the service they render to commerce are called *trade-winds*.

In mid-ocean in the Atlantic, the *north trades* prevail between latitudes 9° and 30°, and in the Pacific, between latitudes 9° and 26°; and the *south trades* in the Atlantic, between latitudes 4° north and 22° south, and in the Pacific between latitudes 4° north and 23½° south. These limits are, however, not stationary, but follow the sun, advancing northwards from January to June, and retreating southwards from July to December.

9. *Region of Calms.* — The region of calms is a belt of about 4° or 5° in breadth, stretching across the Atlantic and the Pacific, generally parallel to the equator. It is marked by a lower atmospheric pressure than is found to the north and to the south of it in the regions of the trade-winds. It is also characterized by the daily occurrence of heavy rains and severe thunderstorms. The position of the belt varies with the sun.

There are two other regions or belts of calms at the limits of the north and south trades. Except in the Pacific Ocean, these belts are either broken up, so as to appear only in patches, or are completely obliterated by the disturbing influences arising from the unequal distribution of land and water. Of these circumscribed regions of calms, the most interesting is that marked out by the high pressures in the North Atlantic. This is the region of the *Sargasso Sea*, which is thus characterized not only by its still waters, but also by its still atmosphere. A similar region of calms exists in the South Atlantic. These calms are well known to sailors.

10. *Winds in Middle Latitudes.* — Surface winds will flow from the belts of high pressure not only towards the equatorial belt of low pressure, but also towards the belts of low pressure on the other side. These currents are continually coming to places which have a *less* velocity eastward than their own, and therefore appear to move *eastward.* This, combined with their motion from the equator, tends to make them *southwest* winds in northern latitudes and *northwest* winds in southern latitudes. These are the prevailing winds in these regions, as has been proved by a long series of observations, but, owing to various disturbing causes, they are much less uniform and constant than the trade-winds. This is especially true of the northern region.

There will also be surface winds blowing from the poles towards these same belts of low pressure. Of course there will be upper currents in opposite directions to all these surface winds.

11. *Winds of the Northern Atlantic.* — It is found that wherever there is a *centre* of low pressure the winds blow towards it, not directly, but *spirally*, and somewhat to the *right* of it. We have an illustration of this in the winter winds of the northern

Atlantic, when there is a centre of low pressure near Iceland. Along the North American coast the prevailing winds are from the N. W. At the more northern places the general direction is more northerly, while farther south it is more westerly. In the Atlantic, between Great Britain and America, the direction is nearly S. W.; this is also nearly the direction in France, Belgium, and the south of England. At Dublin, and in the south of Scotland, it is about W. S. W.; at Copenhagen it is S. S. W.; at St. Petersburg it is nearly S.; and at Hammerfest, near the North Cape in Norway, it is S. S. E. We thus see that the whole atmosphere flows in towards and upon the region of low pressure round Iceland, — not directly towards the region of lowest pressure, but in a direction a little to the right of it. We can now understand why it is that the prevailing winds in North America at this season are N. W., while in Greenland and in Great Britain a N. W. wind is scarcely known.

It is mainly to this low pressure which draws over Great Britain the S. W. winds from the warm waters of the Atlantic, that this island owes its mild, open, and rainy winters. It is the same pressure which gives Russia and Central Europe their severe winters, since on account of it a slow, steady air-current from the cold regions of Northern Asia is drawn westward over those parts of Europe. Finally, the same low pressure draws over British America and the United States, by the N. W. wind, the cold, dry currents of the polar regions. In the State of Maine the mean January temperature is about 23°, whilst on the coast of England, 10° farther north, it is as high as 40°.

12. *Winds of Asia and North America.* — It will be seen, from the position of the centres of high and low pressure, that in winter the general direction of the winds must be *outward* from the continents of North America and Asia; while in summer it is *inward.* Thus, in winter, the prevailing wind of New England is N. W.; in Texas, N.; and in Oregon, S. E. In summer, the prevailing winds in Oregon are N. W.; in Texas, S.; and on the eastern coast of the United States, S. and S. W. In Asia these regular changes in the direction of the winds are even more marked.

13. *Monsoons.* — The term *monsoon*, derived from the Arabic word *mausim*, a set time or season of the year, has been long

applied to the prevailing winds in the Indian Ocean, which blow from the S. W. from April to October, and from the N. E., or opposite direction, from October to April. During the summer, when the sun is north of the equator, the continent of Asia becomes heated to a much greater degree than the Indian Ocean, which in its turn is warmer than Australia and South Africa. Hence, as the heated air of Southern Asia expands and rises, and the pressure is thereby reduced nearly half an inch below the average, colder air from the S. flows in to take its place, and thus a general movement of the atmosphere of the Indian Ocean sets in towards the N., giving a *southerly* direction to the wind. But as the wind comes from parts of the globe which revolve quicker to those which revolve more slowly, it gets a westerly direction. The combination of these two directions results in the S. W. monsoon, which accordingly prevails there in summer. Since, during winter, when the sun is south of the equator, Asia is colder than the Indian Ocean, and the pressure is thereby increased nearly half an inch above the average, a general movement of the atmosphere sets in towards the S. and W. As this is the same direction as the ordinary trade-wind, the result during winter is not to change the direction of that wind, but only to increase its velocity. Thus, southward of the equator, owing to the absence of large tracts of land, the S. E. trades prevail throughout the year; while north of the equator, in the east, we find the S. W. monsoon in summer and the N. E. in winter. It is only in summer and north of the equator that great changes are effected in the direction of the trade-winds.

Similar, though less strongly marked monsoons prevail off the coasts of Upper Guinea in Africa, and Mexico in America.

STORMS.

14. *Storms.* — We have now considered the general atmospheric disturbances caused by the accumulation of heat and moisture in the air over large regions of the globe. In addition to these general disturbances there are local disturbances of the same kind, called *storms*. When the air over any considerable tract becomes excessively heated and humid, it rises and

overflows, producing a local centre of minimum pressure. Surface winds set in towards this centre from all sides in a spiral direction; as the humid air rises it becomes cooled, and its moisture is precipitated as rain or snow. A large amount of heat is thus set free, which causes the air to expand still more. Sometimes these storms remain stationary, but they generally move forward in an easterly direction.

The storms of North America usually have their rise in the region east of the Rocky Mountains, travel eastward towards the coast, and cross the Atlantic. They are preceded by a high temperature and a moist air, and followed by a low temperature and a dry air. When the storm is approaching, the wind sets in from the east, and there is usually the heaviest fall of rain before the centre of the storm arrives. In this centre there is usually a calm, and often considerable clear sky. As the centre passes, the wind suddenly veers round to the west, and a short, heavy fall of rain follows; the temperature rapidly falls, and the barometer rapidly rises. When the centre of the storm passes to the north, the wind sets in from the southeast, and veers round by the south to the southwest. When the centre of the storm passes to the south, the wind sets in from the northeast, and veers round by the north to the northwest.

When a great storm begins near the Mississippi, the wind at St. Louis will be easterly, while farther east it will be westerly. This easterly wind travels eastward with the storm; that is, in a direction *opposite* to that in which it blows. The westerly wind which follows the storm travels along with it; that is, in the *same* direction as that in which it blows.

The storms of America are usually very long in a north and south direction, and travel side foremost; while the storms of Europe are either circular or slightly oblong in the direction of their motion. The latter are followed by less depression of temperature than those of America.

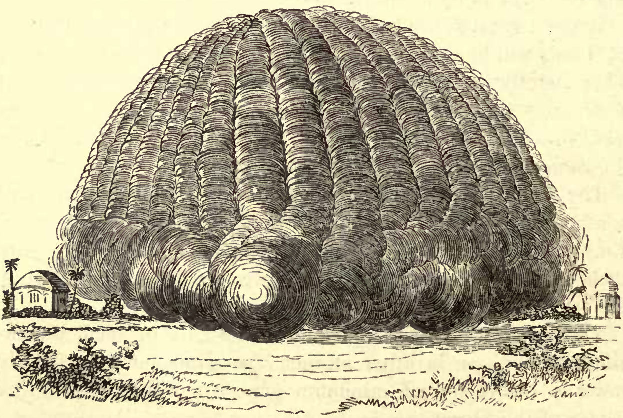
Tornadoes are very violent storms, usually of small dimensions. Here, as in other storms, the wind sets in spirally towards the region of minimum pressure, which is also the centre of the storm.

15. *Whirlwinds.* — *Whirlwinds* are in several respects very different from the storms already described. They seldom last

longer than a minute, sometimes only a few seconds; their breadth varies from twenty to a few hundred yards; their course seldom exceeds 25 miles in length; and while they last the changes of the wind are sudden and violent. The direction of the eddy of the whirlwind, especially when of small diameter, differs from the rotation of the winds in a storm, in the fact that it is not uniform, but depends on the direction of the stronger of the two winds which give rise to it. Thus, suppose a whirlwind be produced by the rushing of a north wind against a south wind, then, if the north wind be the stronger and on the west, the whirl will be in the direction of the hands of a watch, but if the south wind be the stronger the eddy will turn in the opposite direction.

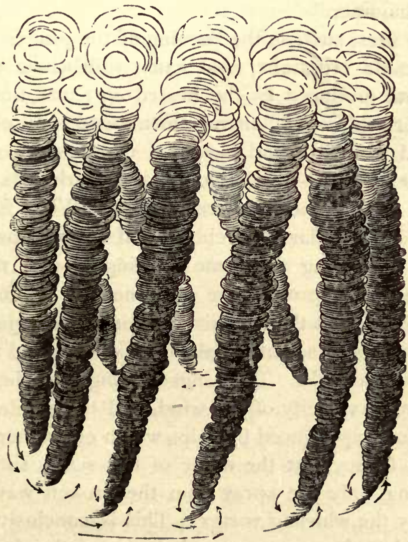
Whirlwinds are often originated in the tropics during the hot season, especially in flat, sandy deserts, which, becoming unequally heated by the sun, give rise to numerous ascending columns of air. In their contact with each other, these ascending currents give rise to eddies, thus producing whirlwinds which carry up with them clouds of dust. Of this description are the *dust-whirlwinds* of India, illustrated in Figures 227 and 228.

Fig. 227.



The large arrows in Figure 228 show the rotation of the whole whirlwind round its axis, while the small arrows show the rotation of each column round its own axis. Figure 227 shows the general appearance of a dust-whirlwind as seen from a distance. A dust-storm is caused by a number of whirlwind columns moving together over the earth. The storm generally comes on with-

Fig. 228.



out warning from any direction, and the barometer is said not to be perceptibly affected by it. A low bank of dark cloud is seen in the horizon, which rapidly increases, and, before the spectator is aware, the storm bursts upon him, wrapping everything in midnight darkness. An enormous quantity of dust is whirled aloft, which is sometimes broken into distinct columns, each whirling on its axis. Violent gusts or squalls succeed each other at intervals, which gradually become weaker, and at the close of the storm a fall of rain generally takes place. The air is often highly electrical, arising probably from the friction of the dust-laden currents against each other. The *Simoom* may be regarded as in part a whirlwind or a succession of whirlwinds of this description. Sir S. W. Baker thus graphically describes the behavior of the dust-whirlwinds which occur in Nubia in April, May, and June: — "I have frequently seen many such columns at the same time in the boundless desert, all travelling or waltzing in various directions, at the fitful choice of each whirlwind; this vagrancy of character is an undoubted proof to the Arab mind of their independent and diabolical character."

Extensive fires, such as the burning of the prairies in America, and volcanic eruptions, also cause whirlwinds by the upward currents produced by the heated air; and these, as well as the other whirlwinds already mentioned, are occasionally accompanied with rain and electrical displays.

16. *Waterspouts.* — Waterspouts are whirlwinds occurring over the sea or over sheets of fresh water. When fully formed they appear as tall pillars stretching from the sea upward to the clouds, and exhibiting the same whirling motion round their axes, and the same progressive movement of the mass, as the dust-whirlwinds. As they consist of vortices of wind in rapid motion, the sea is tossed into violent agitation round their bases as they career onwards. The danger arising from them consists in the enormous velocity of the wind, and the sudden changes in its direction experienced by ships which encounter them. It is a popular fallacy that the water of the sea is sucked up by them, it being only the spray from the broken waves that is carried up by the whirling vortex. This is conclusively proved by the fact that the water poured down on the decks of vessels by waterspouts is either fresh or only slightly brackish.

THE MOISTURE OF THE ATMOSPHERE.

17. *The Two Atmospheres of Air and Vapor.* — The gaseous envelope surrounding the earth may be considered as composed of two distinct atmospheres, — an atmosphere of dry air, and an atmosphere of vapor. The dry air is always a gas, and its quantity is constant from year to year; but the vapor of water does not always remain in the gaseous state, and the quantity present in the atmosphere is, by the processes of evaporation and condensation, varying every instant.

18. *Evaporation.* — Vapor is continually passing into the air

from the surface of water and moist bodies at all temperatures by the silent process of *evaporation*. Evaporation also takes place from the surface of snow and ice. By the increase of temperature the elastic force of the vapor in the atmosphere is increased, and with it the rate of evaporation. The atmosphere can contain only a certain amount of vapor, according to the temperature; hence, when it is *saturated* with moisture, evaporation ceases. Conversely, evaporation will be greatest when the air is perfectly free from vapor. Since atmospheric currents remove the saturated air and substitute dry air, evaporation is much more rapid in windy than in calm weather. Though the quantity of vapor required to saturate a given space is the same, whether it be filled with air or be a vacuum, yet the time taken to saturate it increases with the pressure on the surface of the liquid. When water evaporates into a vacuum, the maximum density of the vapor is acquired at once; but when it evaporates into air, it is not acquired till some time has elapsed. And since every addition to the vapor increases the pressure, the rate of evaporation is, under these circumstances, continually diminishing.

19. *Loss of Heat by Evaporation.*— We have learned (217) that when a liquid passes into the gaseous form, a large quantity of heat becomes *latent;* and that this heat becomes *sensible* again when the vapor returns to the liquid state. The ocean loses more heat from evaporation than the land, because the quantity evaporated from its surface is much greater. Again, since more rain falls on land than on sea, especially in hilly and mountainous countries, the temperature of the air over the land will be still further raised by the heat thus given out. This is one of the reasons why the mean temperature of the northern hemisphere is higher than that of the southern.

It is for this reason that the sensible temperature depends on the humidity of the air. Dry air promotes evaporation from the surface of the body, and seems cold; while moist air impedes this evaporation, and seems warm. When the air is both hot and moist, as in the dog-days, it is peculiarly oppressive. It is because the winds promote evaporation that the air seems cooler on a windy day than on a still one, though the temperature may be the same.

20. *Effect of Drainage on the Temperature of the Soil.*— Theory would lead us to suppose that drained land would have a higher temperature than undrained land, because, being drier, it loses less heat by evaporation ; and experiments have confirmed this.

21. *Dew.* — After the sun has set, the earth is continually radiating heat into space, and is receiving little or none in return. As it cools down, it cools the layer of air nearest to it, and causes it to deposit its moisture in the form of *dew.* In the same way, in hot weather, moisture collects on the outside of a pitcher of ice-water. The cold surface of the pitcher cools the air nearest it so much that it compels it to give up a part of its moisture.

Every one has noticed that dew collects on some substances more readily than on others. This is because they are better radiators, and therefore cool sooner.

Dew does not collect on a cloudy night, or under a roof or shed, because the heat is sent back by the clouds and the roof as fast as it is radiated from the earth.

There is no dew on a very windy night, because the layer of air near the earth is continually changing, and does not become cool enough to give up its moisture.

22. *Dew-point.* — The ascertaining of the dew-point is of great practical importance, particularly to horticulturists, since it shows the point near which the temperature during the night will cease to fall. For when the air has been cooled down by radiation to this point, dew is deposited, heat is given out, and the temperature of the air rises. But as the cooling by radiation proceeds, the air again falls to, or slightly under, the dew-point ; dew is now again deposited, heat liberated, and the temperature raised. Thus the temperature of the air in contact with plants and other radiating surfaces may be considered as gently oscillating about the dew-point. For if it rises higher, the loss of heat by radiation speedily lowers it, and if it falls lower by ever so little, the heat liberated by the formation of dew as speedily raises it. The dew-point, then, determines the minimum temperature of the night ; and if this point be found by means of the hygrodeik (256), the approach of low temperature or of frost may be foreseen and provided against.

23. *Elastic Force of Vapor.*—In an atmosphere of pure steam, its force at the earth's surface is the pressure it exerts; and in an atmosphere of vapor and air perfectly mixed, the elastic force of each at the surface of the earth is the pressure of each. Hence the elastic force of watery vapor would be the pressure of the whole vapor in the atmosphere over the place of observation. This is expresssed in inches of mercury of the barometric column. It is greatest within the tropics, and diminishes towards the poles. It is greater in the atmosphere over the oceans, and decreases as we advance inland. It is greater in summer than in winter, and greater at midday than in the morning. It also diminishes with the height, but the average rate at which it diminishes is not known. Balloon ascents have thrown some light on the question, but the observations are far too few for determining the *mean rate* of the decrease. The chief point established is, that the decrease is generally very far from uniform.

MISTS, FOGS, AND CLOUDS.

24. *Mists and Fogs.* — Mists and fogs are visible vapors floating in the air near the surface of the earth. They are produced in various ways, — by the mixing of cold air with air that is warm and moist, or generally by whatever tends to lower the temperature of the air below the dew-point.

During a calm, clear night, when the air over a level country has been cooled by radiation, and dew begun to be deposited, the portion of the air in contact with the ground is lowered to the dew-point, and thus becomes colder than the air above it. Since there is nothing to disturb the equilibrium and give rise to currents of air, and no cause in operation which can reduce the temperature much below the point of saturation, the air within a few feet of the surface remains free from mist or fog. But if the ground slopes, the cold air, being heavier, must necessarily flow down and fill the lower grounds; and since it is colder than the saturated air which it meets with in its course, it will reduce its temperature considerably below the point of saturation, and thus produce *mist*, or *radiation fog*, as it is sometimes termed. When a lake, river, or marsh fills up the valley, the air may become re-saturated, giving rise to denser fogs.

On the other hand, when the low grounds are sandy or dry, mist is less frequently produced.

When an oceanic current meets a shoal in its course, the cold water of the lower depths is brought to the surface, and in all cases where its temperature is lower than the dew-point of the air, fogs are formed over the shoal. For a similar reason icebergs are frequently enveloped in fogs. In like manner mist is sometimes seen to rise from rivers whose temperature is lower than that of the air. Thus the waters of the Swiss rivers which issue from the cold glaciers cool the air in contact with them below the point of saturation, and mist is thereby often produced. So, also, such rivers as the Mississippi, which flow directly into warmer latitudes, and are therefore colder than the air above them, are often covered with mist or fogs.

When rivers are considerably *warmer* than the air, they give rise to fogs, because the more rapid evaporation from the warm water pours more vapor into the atmosphere than it can hold, and the surplus is condensed into mist by the colder air through which it rises. Thus deep lakes, and rivers flowing out of them, are in winter generally much warmer than the air, and hence when the air is cold and its humidity great they are covered with fogs. When Sir Humphrey Davy descended the Danube in 1818, he observed that mist was always formed during the night, when the temperature of the air on shore was from 3° to 6° lower than that of the stream; but when the sun rose, and the temperatures became equal, the mist rapidly disappeared.

The densest fogs occur during the cold months in large towns built on rivers, — the causes which produce fogs being then at the maximum. The peculiar denseness of the London November fogs is caused by the warmth of the river-bed, and it is increased by the sources of artificial heat which London affords; and since the temperature is falling everywhere, and the humidity is then great, the vapor of the atmosphere is quickly and copiously condensed by the gently flowing cold easterly winds which generally prevail in November.

In all these cases the fogs are confined to the basin of the river or lake where they are formed, and do not extend far up into the atmosphere. There are, however, other fogs that spread over large districts, like the fogs which often accompany the breaking up of frosts in winter. When the humid southwest wind has gained the ascendency, and is now advancing over the earth's surface as a " light air," it is chilled by contact with the cold ground, and its abundant vapor thereby condensed into a wide-spread mist.

Mountains are frequently covered with mist. Since the pressure and consequently the temperature of the air falls with the height, it follows that as warm air is driven up the slopes of the mountain by the wind, it becomes gradually colder, and its capacity for moisture is diminished until condensation takes place, and the mountain is swathed in mist. Mists often appear sooner on the parts of hills covered with trees than elsewhere. This happens especially when the mist begins to form after midday, because then the temperature of the trees is lower than that of the grassy slopes. Mists also linger longer over forests, probably on account of the increased cold arising from the large extent of evaporating surface presented by their leaves when drenched with mist. Occasionally the summit of a hill or an isolated peak is wrapped in mist, while elsewhere the atmosphere is clear; and though a breeze be blowing over the hill, still

> " Overhead
> The light cloud smoulders on the summer crag,"

apparently motionless and unchanged. This phenomenon is easily explained. The temperature at the top is below the dew-point of the atmospheric current. Hence when the air rises to this region its moisture is condensed into mist, which is borne forward over the top of the hill and down the other side, acquiring heat as it descends, till it is again dissolved and disappears. Meanwhile its place is constantly supplied by fresh condensations which take place as the current, rising to the height of the mist, falls below the temperature of saturation. Thus, though the mist on the top of the hill appears to remain motionless and unchanged, the watery particles of which it is composed are continually undergoing renewal.

25. *Clouds.* — Clouds are visible vapors floating in the air at a considerable height; thus differing from mists and fogs, which float near the surface. Both arise from the same causes.

During the warmest part of the day, when evaporation is greatest, warm, moist air-currents are constantly ascending from the earth. As they rise in succession, the moist air is pushed high up into the atmosphere, and, losing heat by expansion, a point is at length reached when it can no longer retain the moisture with which it is charged ; hence condensation takes place, and a cloud is formed, which increases in bulk as long as the air continues to ascend. But as the day declines, and evaporation is checked, the ascending current ceases, and, the temperature falling from the earth's surface upwards, the lower stratum of air contracts, and consequently the whole mass of air begins to descend, and the clouds are then dissolved by the warmth they acquire in falling to lower levels. The whole of this process is frequently seen on a warm summer day. In the morning the sky is cloudless, or nearly so ; as the heat becomes greater, clouds begin to form before noon and gradually increase in numbers and size ; but, as the heat diminishes, they contract their dimensions, and gather round the setting sun, lit up with the fiery splendors of his beams. In a short time they disappear, and the stars come out, shining in a cloudless sky.

Balloon ascents, as well as observations of the clouds, have shown that the whole atmosphere, to a great height, is constantly traversed by many aerial currents, one above another, and flowing in different and frequently in opposite directions. Masses of air of different temperatures thus frequently combine together ; and since the several portions when mingled cannot hold the same quantity of vapor that each could retain before they were united, the excess is condensed and appears as cloud.

But again, when a dry and heavy wind begins to set in, or take the place of a moist and light wind, it generally does so by edging itself beneath the moist wind and forcing it, as with a wedge, into the upper regions of the atmosphere, where condensation rapidly follows, and dense black clouds, often heavily charged with rain, are formed. This is a frequent cause of cloud and rain in Great Britain, when the cold, heavy east wind, or polar current, thrusts high up into the air the rain-bringing southwest wind, causing it to darken the sky and pour its surplus moisture in torrents of rain.

Currents of air driven up the sloping sides of hills and mountains by the winds often cause the formation of clouds (24).

26. *How Clouds are suspended in the Air.* — The example of a cloud appearing to rest on the top of a hill though a strong wind be blowing at the time (24) suggests how clouds are suspended in the air. The cloud itself may appear stationary or suspended, but the particles of which it is composed are undergoing constant renewal or change. The particles are upheld by the force of the ascending current in which they are formed; but when that current ceases to rise, or when they become separated from it, they begin to fall through the air by their own weight, till they melt away and are dissolved in the higher temperature into which they fall. Hence, as Espy has reasoned, *every cloud is either a forming cloud or a dissolving cloud.* While it is connected with an ascending current, it increases in size, is dense at the top, and well defined in its outlines; but when the ascending current ceases, the cloud diminishes in size and density.

When a cloud overspreads the sky, its lower surface is for the most part horizontal, or more generally it seems as if it was an impression taken from the contour of the earth's surface beneath it. This arises from the high temperature of the air below the cloud, which is sufficient to dissolve the particles as they descend below its level.

27. *Classification of Clouds.* — Clouds are divided into seven kinds; three being simple, the *cirrus*, the *cumulus*, and the *stratus;* and four intermediate or compound, the *cirro-cumulus*, the *cirro-stratus*, the *cumulo-stratus*, and the *cumulo-cirro-stratus* or *nimbus*.

These forms of clouds, with the exception of the *nimbus*, are represented in the plate on page 341. The one marked by *one* bird is the *cirrus;* by *two* birds, the *cirro-cumulus;* by *three*, the *cirro-stratus;* by *four*, the *cumulus;* by *five*, the *cumulo-stratus;* by *six*, the *stratus*.

28. *Cirrus Cloud.* — The *cirrus* (or *curl*) cloud consists of parallel, wavy, or diverging fibres which may increase in any or in all directions. Of all clouds it has the least density, the greatest elevation, and the greatest variety of extent and direction, or figure. It is the cloud first seen after serene weather, appearing as slender filaments stretching like white lines pencilled across the blue sky, and thence propagated in one or

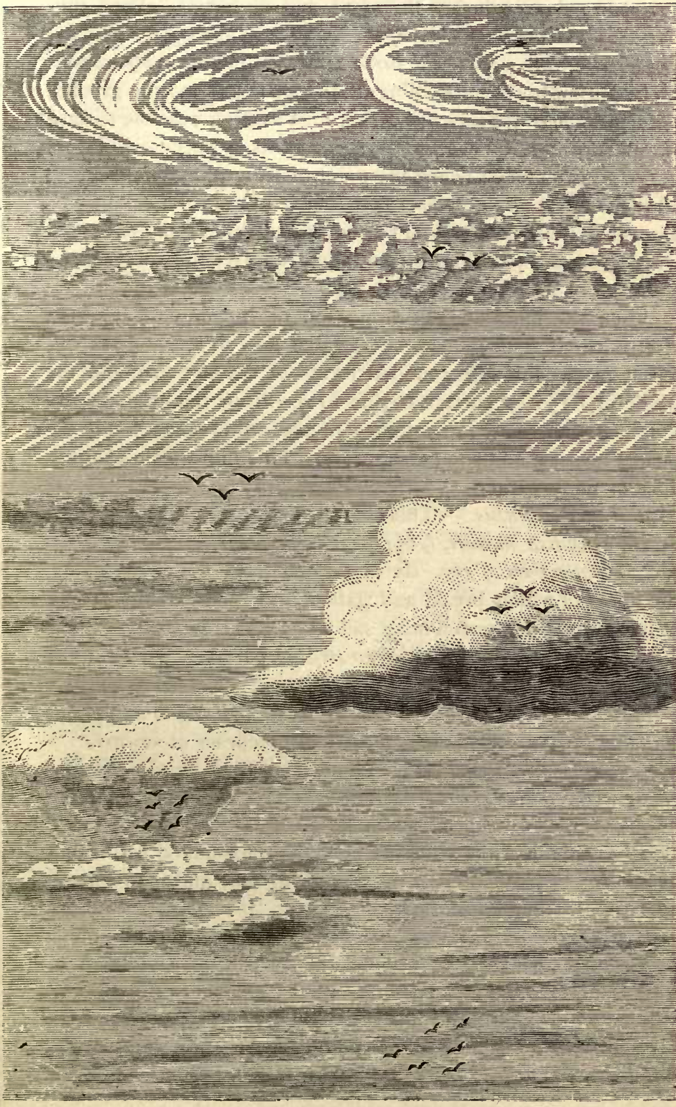
more directions, laterally, or upward, or downward. Sometimes the thin lines of cloud are arranged parallel to each other, the lines lying in the northern hemisphere from north to south, or from southwest to northeast; sometimes they diverge from each other in the form of the tail of a horse; while at other times they cross each other in different ways, like rich, delicate lace-work. It is probable that the fine particles of which this cloud is composed are minute crystals of ice or snow-flakes. The duration of the cirrus varies from a few minutes to many hours. It remains for a short time when formed in the lower parts of the atmosphere and near other clouds, and longest when it appears alone in the sky, and at a great height.

The cirrus, though apparently motionless, is closely connected with the movements of the great atmospheric currents, and is therefore a most valuable prognostic of stormy weather.

29. *Cumulus.* — This name is applied to convex or conical *heaps* of clouds increasing upwards from a horizontal base. They are usually of a very dense structure; are formed in the lower regions of the atmosphere; and are carried along in the current next the earth. The cumulus has been well called the *cloud of the day*, being caused by the ascending currents of warm air which rise from the heated ground. Its beginning is the little cloud not bigger than a man's hand, which is the nucleus round which it increases. The lower surface remains roughly horizontal, while the upper rises into towering heaps, which may continue comparatively small, or swell into a size far exceeding that of mountains.

When these clouds are of moderate height and size, of a well-defined curved outline, and appear only during the heat of the day, they indicate a continuance of fair weather. But when they increase with great rapidity, sink down into the lower parts of the atmosphere, and do not disappear towards evening, *rain* may be expected. If loose fleecy patches of cloud begin to appear thrown out from their surfaces, the rain is near at hand.

30. *Stratus.* — The *stratus*, as its name implies, is a widely-extended, continuous *layer* or sheet of cloud, increasing from below upwards. It is, besides, the lowest sort of cloud, its lower surface commonly resting on the earth. The stratus may be called the *cloud of night*, since it generally forms about sun-



CLOUDS.

set, grows denser during the night, and disappears about sunrise. It is *caused by the vapors which rise during the day, but towards evening fall to the earth with the falling temperature.* Since during night the cooling of the air begins on the ground, the stratus first appears like a thin mist floating near the surface of the earth ; it thence increases upwards as successive layers of the air are cooled below the point of saturation. It includes all those mists already described, which in the calm evening of a warm summer day form in the bottom of valleys and over low-lying grounds, and then spread upwards over the surrounding country like an inundation.

When the morning sun shines on the upper surface of the stratus cloud, it begins to be agitated and to heave up in different places into the rounded forms of the cumulus, and the whole of its lower surface begins to rise from the ground. As the heat increases, it continues to ascend, breaks up into detached masses, and soon disappears. This indicates a continuance of fine weather.

31. *Cirro-cumulus.* — This cloud is composed of well-defined, *small, roundish masses, lying near each other, and quite separated by intervals of sky.* It is formed from the cirrus cloud, the fibres of which break, and gather into these small masses. It is commonly known among sailors as a *mackerel sky.*

32. *Cirro-stratus.* — The *cirro-stratus* partakes partly of the characteristics of the cirrus and stratus. It consists of *long, thin, horizontal clouds, with bent or undulated edges,* and either separate or in groups. It is a marked precursor of storms.

33. *Cumulo-stratus.* — This cloud is formed by *the blending of the cirro-stratus with the cumulus,* either among its piled-up heaps, or spreading underneath its base as a horizontal layer. It is formed when the cumulus becomes surrounded with small fleecy clouds just before rain begins to fall, and also on the approach of thunder-storms.

34. *Cumulo-cirro-stratus, or Nimbus.* — This is the well-known *rain-cloud,* consisting of a cloud, or system of clouds, from which rain is falling. It sometimes has its origin in the cumulo-stratus, which increases till it overspreads the sky, and becomes black or bluish-black in color ; but, this soon changing to gray, the nimbus is formed, and rain begins to fall.

Its name, *cumulo-cirro-stratus*, suggests the way in which it is usually formed. At a considerable height, a sheet of cirro-stratus cloud is spread out, under which cumulus clouds drift from the windward; these rapidly increase and unite into a continuous gray mass, from which the rain falls. The breaking up of this gray mass indicates that the rain will soon cease.

When a rain-cloud is seen approaching at a distance, *cirri* appear to shoot out from its top in all directions; and the more copious the rain-fall, the greater is the number of these cirri.

RAIN, SNOW, AND HAIL.

35. *Rain.* — Whatever lowers the temperature of the air may be considered as a cause of rain. It is *chiefly brought about by the ascent of air into the higher regions of the atmosphere.* Moist air-currents are forced up into the higher parts of the atmosphere by colder, drier, and therefore heavier, wind-currents which get beneath them. Ranges of mountains also oppose their masses to the winds, so that the air forced up their slopes is cooled, and its vapor condensed into showers of rain or snow. Moist air-currents are also drawn up into the higher regions of the atmosphere over the area of least pressure at the centre of storms; and in such cases the rain-fall is generally very heavy. The temperature of the air is lowered, and the amount of the rain-fall increased, by those winds which convey the air to higher latitudes. This occurs in temperate regions, or in those tracts traversed by the return trade-winds, which in the north temperate zone blow from the southwest, and in the south temperate zone from the northwest. *The meeting and mixing of winds of different temperatures* is also a cause of rain, since the several portions, when combined into one, cannot hold as much vapor as before. The rain-fall is also increased if the prevailing winds are directly from the sea, and are therefore moist; but it is diminished if they have passed over large tracts of land, particularly mountain-ranges, and are therefore dry. The quantity of rain is influenced by *sandy deserts*, which allow radiation, by day or night, to take immediate effect in raising or depressing the temperature; and also by *forests*, which retard or counteract radiation.

Rain rarely or never falls in certain places, which are, on that account, called *rainless regions;* as, for example, the coast of Peru, in South America, the Sahara in Africa, and the desert of Gobi, in Asia.

The Sahara is bounded on the north and on the south by ranges of mountains. When the northeast trade-wind strikes the northern range, a part of its vapor is condensed. As it moves southward, it reaches warmer latitudes, where there is a greater capacity for moisture. Since there are no opposing winds to force it upwards, it sweeps on across the vast sandy plain until it arrives at the southern mountains, where its vapor is precipitated in abundant rains. In the few spots in the desert where hills or mountains occur, there are occasional rains.

On the desert of Gobi, the prevailing winds are from the southeast, and are very dry, because they have precipitated nearly all their moisture in passing over the Himalaya Mountains.

The rainless district in Peru is caused by the Andes, which condense nearly all the vapor of the southeast trade-wind in copious rains on their eastern slopes.

On the other hand, in such places as Chili and Patagonia, it rains almost every day.

36. *Rain-fall within the Tropics.* — At places within the tropics, where the trade-winds blow regularly and steadily, the rain-fall is small. Since these winds come from higher latitudes, the temperature is increasing, and they are thus more likely to take up moisture than to part with it. Where, however, the trade-winds are forced up the slopes of mountain ranges, they bring rain in copious showers.

The tropical belt, known as *the region of calms* (see page 326) is the region of *constant rains.* Here the sun almost invariably rises in a clear sky; but about midday clouds gather, and the whole face of the sky is soon covered with black clouds, which pour down prodigious quantities of rain. Towards evening the clouds disappear, the sun sets in a clear sky, and the nights are serene and fine. The reason of this is, that the air, being greatly heated by the vertical rays of the sun, ascends, drawing with it all the vapor which the trade-winds have brought with them, and which has been largely increased by the rapid evaporation from the belt of calms ; and this vapor is condensed as it rises. The rain is sometimes so copious that fresh water has been collected from the surface of the sea. As evening sets in, the surface of the earth and the air near it being cooled, the ascending currents cease, and the cooled air descends ; the clouds are thus dissolved, and the sky continues clear till the returning heat of the following day.

Over a great part of the tropics disturbing influences draw the trade-winds out of their course, and sometimes, as in the case of the monsoons, give rise to winds which blow from the opposite point of the compass. These winds affect *the rain-fall of India*, and but for them the eastern districts of Hindostan would be constantly deluged with rain, and the western districts constantly dry and arid. As it is, each part of India has its dry and wet seasons, summer being the wet season of the west and interior as far as the Himalaya, and winter the wet season of the east, and especially the southeast.

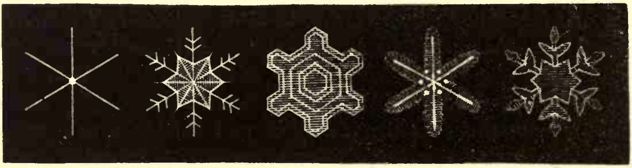
So far as known, *the heaviest annual rain-fall* at any place on the globe is 600 inches on the Khasia Hills. About 500 inches of this fall in seven months, during the southwest monsoons. These hills face the Bay of Bengal, from which they are separated by only 200 miles of swamps and marshes. Hence the southerly winds not only arrive heavily laden with vapor from the Indian Ocean, but they get more moisture in passing over the 200 miles of swamp. They are, therefore, ready to burst in torrents, even before they are suddenly raised, by the hills they encounter, into the cooler regions of the atmosphere.

37. *Snow.* — Snow is the frozen moisture which falls from the clouds when the temperature is 32° or lower. The particles of which snow is composed are crystals, which are usually in the form of six-pointed stars. About 1,000 different kinds of snow-crystals have been already observed, a few of which are shown in Figure 229. The forms of the crystals of the same fall of snow are generally similar to each other. Snow-flakes vary from an inch to .07 of an inch in diameter, the largest being observed when the temperature is near 32°, and the smallest at very low temperatures.

The limit of the fall of snow at any time of the year coincides nearly with 30° N. latitude, which includes almost the whole of Europe. On traversing the Atlantic, this line rises to 45°, but on nearing the American continent it descends to 33°; it rises in the west of America to 47°, and again falls to 40° in the Pacific. Snow is unknown at Gibraltar; at Paris, it falls 12 days on an average annually, and, at St. Petersburg, 170 days.

The *white color* of snow is caused by the combining of the different prismatic rays which issue from the minute snow-crystals. When the crystals are looked at separately, some

Fig. 229.



appear red, others green, purple, and, in short, all the colors of the spectrum; but when a mass of snow is looked at, the different colors blend into white.

Red snow and *green snow* have been occasionally met with in the arctic regions and in other parts of the world. These colors are due to the presence of vegetable organisms, about .001 of an inch in diameter, which grow and flourish in the region of eternal snow.

From its loose texture, and from its containing about ten times its bulk of air, snow is a very bad conductor of heat; and thus is an admirable covering to preserve the earth from the effects of its own radiation. It not unfrequently happens in times of great cold, that the soil is 40° warmer than the surface of the snow which covers it. The flooding of rivers, from the melting of the snow on mountains in spring and summer, carries fertility into regions which would otherwise remain barren wastes.

38. *Hail.* — Hailstones are generally of a conical or of a round shape, and, when cut across, are found to be composed of alternate layers of clear and opaque ice, enveloping a white snowy nucleus. Less frequently they are composed of crystals

radiating from the centre outwards. They vary much in size, some being as small as the smallest shot, while others are several inches in diameter. In August, 1813, hailstones the size of eggs fell upon the British army among the Pyrenees; the storm lasted twenty minutes, and was not accompanied with thunder or lightning. June 4th, 1814, hail, from 13 to 15 inches in diameter, fell in Ohio. In the Orkney Islands, July 24th, 1818, during thunder, a very remarkable shower of hail took place; the stones were as large as a goose's egg, and mixed with large masses of ice.

The origin of hail is not fully understood; but it appears to be formed by a cold current of air forcing its way into a mass of air *much warmer and nearly saturated*, the temperature of the united mass being below the freezing-point. The warm, moist air is easily accounted for, since hail generally falls in summer and during the day; but it is difficult to account for the intensely cold current which is sufficient to reduce the warm saturated mass below 32°.

In mountainous regions, cold currents from the fields of snow, rushing down the sides of the mountains and mixing with the heated air of the valleys, are no doubt frequent causes of hail; and such places are peculiarly subject to hailstorms.

The sudden ascent of moist warm air into the upper regions of the atmosphere, where a cold current prevails at the time, is, in all probability, a common cause of hail. This is confirmed by the sultry, close weather which generally precedes hailstorms, the slight but sudden fall of the barometer, the whirlwinds and ascending currents which accompany them, and the fall in the temperature which follows after the storm has passed.

ATMOSPHERIC ELECTRICITY.

39. *Electricity in the Air.* — The identity of lightning and electricity was first suspected by Wall in 1708, but it was reserved to Franklin to prove it. In 1749, he suggested, as the mode of proof, the erection of pointed metallic conductors properly insulated. Acting on this suggestion, Dalibard erected near Paris a pointed iron rod, 40 feet in length, and insulated; and, on the 10th of May, 1752, obtained electrical sparks from

it. In June of the same year, Franklin, impatient at the delay in erecting the spire for his pointed conductor, tried the experiment of obtaining electricity from the clouds by flying a kite. The kite was held by a hempen string, to the lower end of which a key was attached; and the whole was insulated by tying a silk ribbon to the key, the other end of the ribbon being attached to a post. On the approach of the thunder-cloud, he raised the kite, and soon the fibres of the hempen string began to repel each other; and, at last, when the rain had moistened the string, he had the satisfaction of drawing sparks from the key.

When the sky is cloudless, the electricity is always *positive;* but the intensity increases with the height.

When the sky is clouded, the electricity is *sometimes positive and sometimes negative*, according to the electrified condition of the clouds. In relation to the air, the earth's surface is always negative.

The electricity of the atmosphere is stronger in winter than in summer, increasing from June to January, and decreasing from January to June. It is subject to a double maximum and minimum each day.

40. *Sources of Atmospheric Electricity.* — (1) *Evaporation.* — Electricity is produced when *impure* water is evaporating, or water in which chemical decomposition is going on; none whatever being produced by the evaporation of pure water. Evaporation from water containing an alkali or a salt gives off negative electricity to the air, and leaves positive electricity behind; but when the water contains acid, positive electricity is given off, and negative is left behind. Hence it is supposed that seas, lakes, and rivers are abundant sources of electricity, particularly of the positive sort. (2) *Vegetation.* — The vegetable kingdom is also a source of electricity; (*a*) from the evaporation going on by which water is separated from the sap of the plants, and (*b*) from the giving off of oxygen gas during the day, and carbonic gas during the night. In these cases, positive electricity arises from the plants, and negative is left behind. (3) *Combustion.* — During the process of burning, bodies give off positive electricity, and become themselves negatively electrified. This is frequently seen on a grand scale

during volcanic eruptions. (4) *Friction.* — Wind, by the friction it produces upon terrestrial objects, the particles of dust, and the watery particles which it carries with it, contributes to the electricity of the air. Electricity is not generated if the moisture be in the form of pure vapor.

41. *Effect of the Condensation of Vapor.* — When a great multitude of molecules of vapor are condensed by cold into a drop, or snow-spangle, that drop probably collects and retains on its surface the whole electricity of the molecules from which it is formed. If a thousand such globules coalesce into one, the electricity will be increased a thousand-fold, and, being spread entirely over the surface, will have a tenfold tension. This view (which is Sir John Herschel's) explains the electricity observed in the lower stratum of air when *dew* is being deposited, and the highly electrical state of *fogs* and *clouds.* It also explains the annual fluctuation; for, since in winter the condensation of vapor is greater and more frequent than in summer, the average quantity of electricity will be greater in winter.

42. *Thunder-storms.* — The thunder-storm probably originates, like cloud and rain, in *the condensation of vapor;* but the condensation is more copious and more rapid, so as to bring about an accumulation of a sufficient quantity of electricity. If the condensation is not copious, the electricity will be too weak; and if not sudden, it escapes before enough collects for a discharge.

Thunder-storms occur most frequently within the tropics, and diminish in frequency towards the poles. They are also more frequent in summer than in winter; during day than during night; after midday than before it; and in mountainous countries than in plains. Within the tropics they prevail most in the region of calms and during the rainy season; and least in arid deserts and during the dry season.

43. *Lightning.* — Arago has divided lightning into three kinds; *zigzag lightning*, *sheet lightning*, and *ball lightning.* When the electric flash darts through the air, it takes the path of least resistance; and, since the conducting power of different portions of the atmosphere is unequal, the lightning frequently appears *zigzag.* When branches are given off at different

points of its course, the lightning is said to be *forked*. *Sheet-lightning* is the most common, appearing as a glow of light illuminating the sky. The flashes often follow each other in quick succession, and the thunder which accompanies them is low and at a considerable distance. Analogous to this is *silent lightning*, frequently termed *heat lightning*, which generally occurs during serene summer evenings, lighting up the sky fitfully for hours, with repeated faint flashes; it is not attended with thunder. It is probable that this kind of lightning is almost always the reflection of the lightning of distant storms from the vapor of the upper regions of the atmosphere, the storms themselves being so far off that their thunder cannot be heard. *Ball lightning* is the least common. It appears as a globular mass, moving slowly or sometimes remaining stationary, and in a short time explodes with violence. It has not yet been satisfactorily explained. Professor Wheatstone has shown that the duration of a flash of lightning is less than the thousandth part of a second. A wheel was made to rotate so rapidly that the spokes were invisible; on being lighted up with the electric flash, the duration of the flash was so brief that the wheel appeared quite stationary, even though rotating with the utmost speed possible.

44. *Thunder.* — Thunder is probably the noise produced by the instantaneous rushing of the air to fill the vacuum left by the lightning along the path of the discharge. The sound emitted by flames is a familiar illustration of a similar phenomenon. Flashes of lightning frequently extend two or three miles in length; and since the thunder is produced at every point along its course nearly at the same instant, the prolonged rolling noise of thunder arises from the different intervals of time it takes the sound to reach the ear. For since sound travels at the rate of 1,090 feet per second, it is first heard from the nearest point of the flash, later and later from points more distant, so that the combined effect is a continued peal of thunder. The direction and character of the peal will depend on the length of the flash, and the greater or less obliquity of its course in relation to the observer. Reverberations from clouds and from mountains frequently heighten the effect and prolong the peal. From the rate at which sound travels, if the thunder is not

heard till five seconds after the flash, the distance is about a mile. Thunder has not been heard at a greater distance than 14 miles from the flash.

45. *Effects of Lightning.* — The great proportion of electrical discharges pass into the air, or into other clouds less highly electrified ; a very few only take place between the cloud and the earth. The destructive effects of this latter class are known to all. By the electric discharge innumerable lives have been destroyed, the strongest trees rent to pieces, heavy bodies displaced, iron and steel magnetized, metals and rocks softened and fused, and combustible substances set on fire. When the thunderbolt falls upon sand it usually produces *fulgurites* or *fulminary tubes*, which are silicious tubes of various sizes vitrified internally.

46. *Return Shock.* — This shock sometimes proves fatal to living beings, even at great distances from the place where the electric discharge takes place. It is caused by the inductive action of the electrified cloud on bodies within the sphere of its influence, by which they become charged with the electricity opposite to that of the cloud. Hence, when the cloud has discharged its electricity into the ground, the induction ceases and a rapid change takes place in bodies from the electrified to the neutral state, thus causing the concussion of the return shock.

47. *Lightning-Rods.* — The lightning-rod was introduced by Franklin in 1755 as a means of protecting buildings from the destructive effects of electricity. The advantage gained by it consists not in protecting the building in case of a discharge by allowing a free passage for the electric fluid to escape to the earth, for it is but a poor protection in such a case ; but, by quietly and gradually keeping up the communication, it tends to maintain the electric equilibrium, and thus prevent the occurrence of a discharge. The best rods are made of copper not less than three quarters of an inch thick, and pointed at the upper end. They should be of one piece throughout, fastened vertically to the roof of the building, and thence carried down into the ground. The lower extremity should part into two or three branches bent away from the house, and carried sufficiently far into the soil to meet water or permanently moist earth. The conductor should be connected with all metallic

surfaces on the roof or other parts of the building, in order to prevent the occurrence of lateral discharges, or discharges from the conductor to these surfaces, which are often very destructive.

48. *St. Elmo's Fire.* — This meteor is the *Castor and Pollux* of the ancients, and is frequently mentioned in classic writings, from the Argonautic expedition downwards. Cæsar notices its appearance after a storm of hail in these words: "Eadem nocte legionis quintae cacumina sua sponte arserunt." The finest and most beautiful displays occur at sea during storms, when it appears as a light resting on the masts. The light which is seen on a point held near the conductor of an electric machine explains St. Elmo's fire, which takes place when the electricity of a cloud and that of the earth combine, not in flashes of lightning, but slowly and continuously from different points.

49. *The Aurora Borealis.* — The *aurora borealis* is the luminous appearance in the northern sky, which forms, in its most vivid displays, spectacles of surpassing beauty. The aurora is observed also in the neighborhood of the south pole, and is there called *aurora australis.* When fully developed, the aurora consists of a dark segment of a hazy or slaty appearance surmounted by an arch of light, from which luminous *streamers* quiver and dart upwards. Several auroral arches are sometimes seen at once. Sometimes the streamers appear to unite near the zenith, forming what is called the *corona* of the aurora, towards which the dipping needle at the time points.

Auroras are very unequally distributed over the earth's surface. At Havana but six have been recorded within a hundred years. As we travel northwards from Cuba, they increase in frequency and brilliancy; they rise higher in the heavens, and oftener attain the zenith. If we travel northwards along the meridian of Washington, we find on an average near the parallel of 40° only ten auroras annually. Near the parallel of 42°, the average number is twenty annually; near 45°, it is forty; and near 50°, it is eighty. Between this point and the parallel of 62° auroras are seen almost every night, high in the heavens, and as often to the south as the north. Farther north they are seldom seen except in the south, and from this point they diminish in frequency and brilliancy as we advance towards the pole. If we make a like comparison for the meridian of St. Petersburg, we shall find a similar result, except that the auroral region is situated farther northward than it is in America. Auroras are more frequent in the United States than they are in the same latitudes of Europe.

The aurora is of great extent, having been sometimes observed simultaneously in Europe and America. From observations made in the two hemispheres, Professor Loomis thinks it probable that an exhibition of auroral light about one magnetic pole of the earth is uniformly attended by a simultaneous exhibition of auroral light about the opposite magnetic pole.* The height varies from about 45 to 500 miles above the earth.

50. *Relations of the Aurora to Magnetism.* — Many facts point out an evident connection between the aurora and terrestrial magnetism. The magnetic needle is much agitated when the aurora is visible. When the arch is motionless, so is the needle ; but as soon as streamers are shot out, its declination changes every moment, and this happens though the aurora does not appear at the place of observation, but is seen near the pole. Captain M'Clintock, when in the arctic regions, observed that the aurora in all cases appeared to come from the surface of open water, and not in any case from the fields of ice. This favors the idea that it is caused by electrical discharges between the earth and the air, and that these are interrupted by the fields of non-conducting ice.

General Sabine has discovered that magnetic disturbances of the earth are due to the sun, but not to his heat and light ; and are invariably accompanied by the aurora and by electric currents on the surface of the earth. The secular periods of the sun's spots, of the variation of the magnetic needle, and of the frequency of auroras, coincide in a remarkable way, indicating that these phenomena are regulated by astronomical causes.†

OPTICAL PHENOMENA.

51. *The Rainbow.* — For the description and explanation of the *rainbow*, see pages 144 – 147.

* *Treatise on Meteorology*, p. 188.

† See *Handbook of the Stars*, p. 91.

Since rainbows in the morning are always seen in the west, they indicate the advance of the rain-cloud from the west at the time that it is clear and bright in the east; and since the fall of rain at this time of the day when the temperature should be rising is an additional evidence of increasing moisture, a morning rainbow is regarded as a prognostic of a change to wet, stormy weather. On the contrary, the conditions under which a rainbow can appear in the evening are, the passing of the rain-cloud to the east, and a clearing up in the west at the time of day when the temperature has begun to fall, thus further indicating a change from wet to dry weather. Hence the popular rhyme: —

"A rainbow in the morning, —
Sailors take warning;
A rainbow at night
Is the sailor's delight."

52. *Lunar Rainbows.* — Rainbows are also produced by the light of the moon falling on rain-drops, exactly in the same way as solar rainbows. They are by no means of rare occurrence. Owing to the feeble light of the moon the bow is generally without colors; but when the sky is very clear and the moon at the full, the prismatic colors appear, but in subdued splendor.

53. *Coronas.* — The corona is an appearance of faintly-colored rings encircling the moon when seen behind the light, fleecy cloud of the cirro-cumulus. When the corona is perfect, the rings form several concentric circles, the blue prismatic color being nearer the centre than the red. When of large dimensions the ring has generally a whitish, nebulous appearance.

Coronas are also very frequently formed round the sun; but to see them it is necessary to look through smoked glass, or at the image of the sun reflected from still water.

54. *Anthelia.* — *Glories of light*, otherwise called *anthelia*, because formed *opposite the sun*, are sometimes seen when the shadow of an observer is cast on fog; and the shadow of his head is surrounded with the prismatic circles. On one occasion Scoresby saw four colored concentric circles around his shadow, and he observed that the phenomenon was always seen in the polar regions whenever sunshine and fog occurred at the same time.

55. *Halos.* — Halos are circles of prismatic colors around the sun (Figures 230–233) or the moon (Figures 234 and 235),

Fig. 230.

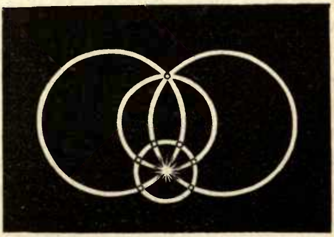


Fig. 231.

Fig. 232.

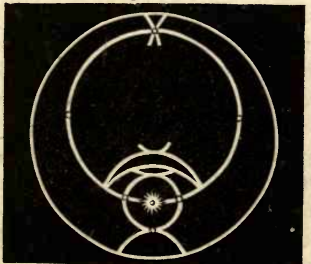


Fig. 233.

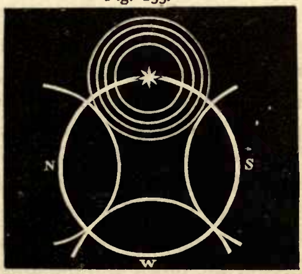


Fig. 234.

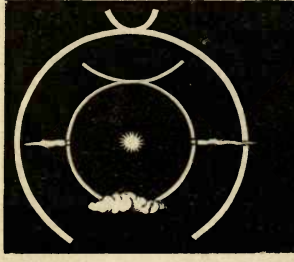
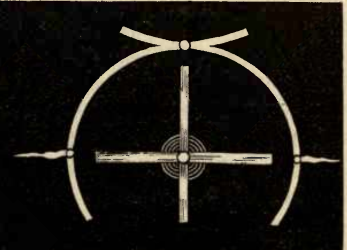


Fig. 235.



but they are perfectly distinct from coronas, with which they should not be confounded. Halos are of comparatively rare occurrence; coronas, on the contrary, may be seen every time a light, fleecy cloud comes between us and the sun or moon. The structure of halos, as seen from the figures, is often very complicated, circle cutting circle with mathematical exactness, the circles being generally very large. The structure of the corona, on the other hand, is simple, the circles concentric, the inner one small, the diameter of the second being double, and that of the third treble, the diameter of the first. In halos, the red prismatic color is next the centre; in coronas, the blue. Halos are formed from the refraction and reflection of the rays of light by the minute snow-crystals of the cirrus cloud; while coronas arise from the interference of the rays passing on each side of the globules of vapor.

56. *Parhelia and Paraselenæ.* — At the points where the circles of the halo intersect, images of the sun or moon generally appear from the light concentrated at these points. The images of the sun are called *parhelia*, or *mock-suns;* and those of the moon, *paraselenæ*, or *mock-moons.* These also exhibit the prismatic colors of the halo.

57. *Colors of Clouds.* — Every one has observed and admired the red and golden clouds which fire the western sky at sunset, and make "the day's dying glory." They are observed to be the accompaniment of cumulus clouds as they slowly sink, while dissolving, down into the lower and warmer parts of the atmosphere; and consequently they disappear from the sky shortly after sunset. Such sunsets are therefore universally regarded as prophetic of fine weather.

A green or yellowish-green tinted sky, on the other hand, is one of the surest prognostics of rain in summer, and snow in winter. The changing tints of the evening sky after stormy weather supply valuable help in forecasting the weather; for, if the yellow tint becomes of a sickly green, more rain and stormy weather may be expected; but if it deepens into orange and red, the atmosphere is getting drier, and fine weather may be looked for.

Some years ago, Forbes showed from experiments that high-pressure steam, while transparent, and *in the act of expansion*, readily absorbs the violet, blue, and part of the green rays, thus letting the yellow, orange, and red pass. Dr. E. Lommel has shown that successive layers of air with visible vapor diffused through them act, so to speak, like sieves, which continually separate the transmitted light more and more perfectly from its more refrangible rays. Hence, in passing through different thicknesses of vapor, the blue rays are first absorbed, then the yellow rays, and finally the red rays. It is in the lower layers of the atmosphere that dust, smoke, watery vapor, and small rain-drops are chiefly suspended. When the sun is high in the heavens, the thickness of the vapor-screen between the sun and the eye is not sufficient to produce any perceptible action on the rays of light, which consequently appear white; but as the sun descends to the horizon the thickness of the vapor is greatly increased, and at sunset it is calculated that the light of the sun has to pass through 200 miles of the air in illuminating a cloud a mile above the earth. Hence, as the rays fall more and more obliquely on the clouds, they appear successively yellow, orange, and finally red. The varied colors often seen at sunset are due to the fact that the clouds appear at different heights and in different parts of the sky, so that various thicknesses of vapor are interposed between them and the sun. At dawn the clouds first appear red; but, as the sun rises higher, the yellow light ceases to be absorbed, and they appear orange, yellow, and finally white. These successive stages of a perfect dawn are well described in Dante's *Purgatorio*: —

> "The dawn was vanquishing the matin hour,
> Which fled before it, so that from afar
> I recognized the trembling of the sea. . . . .
> Already had the sun the horizon reached, ...
> So that the white and the vermilion cheeks
> Of beautiful Aurora, where I was,
> By too great age were changing into orange."
>
> *Longfellow's translation.*

Milton has accurately described the last stage of dawn in *L'Allegro*: —

> ". . . . the great sun begins his state,
> Robed in flames and amber light,
> The clouds in thousand liveries dight."

It is evident that a *high* red dawn may be regarded as a prognostic of settled weather, because the redness seen in clouds at a great height while the sun is yet below the horizon may be occasioned by the great thickness of the vapor-screen through which the illuminating rays must pass before reaching the clouds, and not to any excess of vapor in the air itself. But if the clouds be red and *lowering* in the morning, it may be accepted as a sign of rain, since, the thickness traversed by the illuminating rays being now much less, the red color must arise from an unusual amount of vapor in that stage of partial condensation, when, according to Forbes, the blue rays are absorbed, and the yellow and red pass.

SOURCES AND CONVERSION OF ENERGY.

☞ *This Abridgment of the chapter in the "Astronomy" on "Energy" is inserted for the convenience of teachers who may not use both books.*

1. *Kinds of Energy.* — Every moving body is said to have a *dynamical* energy; and every body which is so situated that it can be moved by the forces acting upon it is said to have a *possible* or *potential* energy. The energy of a visible mass in motion is called *mechanical.* The energy of a moving molecule or atom is called *molecular* or *atomic.*

The energy manifested in the bodies of animals is called *nerve force* or *muscular* energy.

2. *Affinity, Cohesion, and Gravity are the Forces which tend to convert Potential into Dynamical Energy.* — When visible masses are separated, gravity tends to pull them together, and to convert their potential into dynamical energy. When the molecules of a body are separated by melting and boiling, cohesion tends to draw them together again, and thus to convert their potential into dynamical energy, which appears as heat. Again, when the elements of a compound are separated, chemical affinity tends to pull them together, and to convert their potential into dynamical energy, which appears, in ordinary chemical action, as heat and electricity, or, in respiration, as heat and muscular force.

3. *Mechanical Energy may be converted into Heat.* — We

have a familiar illustration of this in the lighting of a friction match. A portion of the energy employed in rubbing the match is converted by the friction into heat, which ignites the phosphorus. Here there is a double transfer of energy. The muscular energy of the arm is converted into mechanical energy in the moving match, and a part of this into heat by the friction.

Before matches were invented, the flint and steel were used for the same purpose. The steel was struck against the flint, and the spark obtained was caught in tinder. A part of the mechanical energy of the steel appeared as heat in the spark.

Indians are said to obtain fire by vigorously rubbing together two pieces of dry wood. In this case, too, the heat is nothing but mechanical energy appearing in a new form.

Iron can be heated red-hot by hammering it. And, generally, heat is developed by friction and percussion.

4. *All Mechanical Energy is ultimately converted into Heat.* — When a falling body strikes the earth, it becomes heated. In this case the whole energy of the body is converted into heat. When bodies are rubbed together, their energy, as we have seen, is converted into heat.

The energy of a running stream is gradually converted into heat by the friction against its banks and bed and among its particles. If it is made to turn the wheels of a factory on its way, the rubbing of the parts of the machinery against each other and against the air, together with the various kinds of work done by the machinery, converts the mechanical energy of the water-wheel into heat.

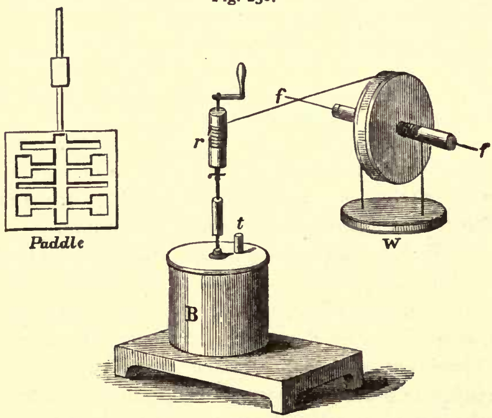
A railway train is really stopped by the conversion of its motion into heat. When this has to be done quickly, the change is hastened by increasing the friction by means of the brakes. On the other hand, in order to prevent the loss of energy while the train is in motion, the axles of the wheels are kept carefully oiled, that they may turn with as little friction as possible.

When unlike substances are rubbed together, a part of the energy is first converted into electricity, but ultimately into heat.

5. *When Mechanical Energy is converted into Heat, the Same Amount of Energy always gives rise to the Same Amount of*

Heat. — This was first shown by Joule, who began his experiments in 1843 and continued them till 1849. He converted mechanical energy into heat by means of friction. He first examined cases of the friction of solids against liquids. The apparatus used for this purpose is shown in Figure 236. *B* is a cylindrical box holding the liquid. In the centre of the box is

Fig. 236.



an upright axis, to which are attached eight paddles like the one shown in the figure. These revolve between four stationary vanes, which prevent the liquid from being carried round. The paddles are turned by means of the cord *r* and the weight *W*. The size of the weight is such that it descends without acquiring any velocity, and hence all its energy is expended in the friction of the paddles. The degree to which the liquid becomes heated by the friction is shown by a thermometer at *t*. Knowing the weight of the liquid, its specific heat, and the rise of temperature during the experiment, the amount of heat generated can be readily calculated.

With this machine Joule found that, whatever the liquid he used, a weight of one pound falling through 772 feet, or 772 pounds falling one foot, generated heat enough to raise one pound of water one degree Fahrenheit in temperature, or one *unit of heat*, as it is called.

He also found that, when solids were rubbed together by the action of a falling weight, one pound falling through 772 feet generated a unit of heat. In this experiment iron discs were made to rotate together, one against the other, in a vessel of mercury.

If a metallic disc be put into rapid rotation and then brought between the poles of a powerful electro-magnet, it soon comes to rest. It will now be found very difficult to turn it, and it becomes heated as it rotates. Joule found in this case, as in the others, that, if the disc is turned by a falling weight, one pound descending 772 feet generates a unit of heat.

The force necessary to raise one pound one foot is called a *foot-pound;* and this is the same force which a pound acquires in falling one foot from a state of rest.

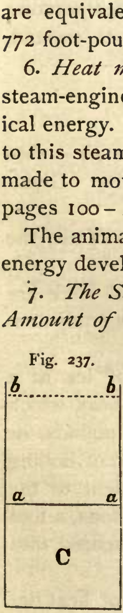
We see, then, that when mechanical energy is converted into heat, the same amount of energy always gives rise to the same amount of heat, and that 772 foot-pounds of mechanical force are equivalent to one unit of heat. For this reason, we call 772 foot-pounds the *mechanical equivalent of heat.*

6. *Heat may be converted into Mechanical Energy.* — The steam-engine is a contrivance for converting heat into mechanical energy. The heat converts the water into steam, and gives to this steam an expansive force; and this expansive force is made to move a piston, as has already been explained (Part I., pages 100 – 102).

The animal body is a machine for converting the molecular energy developed by affinity into mechanical energy.

7. *The Same Amount of Heat always gives rise to the Same Amount of Mechanical Energy.* — In Figure 237, *C* is a box a foot square. Suppose *a a* to be a partition one foot from the bottom, so as to shut in a cubic foot of air. Suppose this partition to be immovable, and the air beneath to be heated. Its elastic force will be increased, but it cannot expand. We will next suppose that *a a* is movable, but without weight, and that the air beneath is heated as before. On raising its temperature 490° its volume will be doubled, and *a a* will of course be raised one foot to *b b*. In raising *a a*

Fig. 237.



one foot it has had to raise the air above it. Now this air presses with a force of 15 pounds upon every square inch, or $15 \times 144 = 2,160$ pounds upon the whole surface. From the specific heat of air, we know that to raise the temperature of a cubic foot of air 490°, when it is free to expand, 9.5 units of heat are required.

But we have seen that a part of the heat which enters a body is used in expanding it, and a part in raising its temperature. In the above experiment, how much heat is used in raising the temperature? This is equivalent to asking how much heat is required to raise the cubic foot of air 490° when it is not allowed to expand. We have learned that the computed velocity of sound in air is less than its observed velocity, and that this is owing to the heat developed in the compressed portion of the sound-wave. From the ratio between the observed and the computed velocity, it is found that the specific heat of air when free to expand must be 1.42 of its heat when not allowed to expand. Hence the heat required to raise the temperature of the cubic foot of air 490°, when it is not allowed to expand, is found by the following proportion to be 6.7 units: —

$$1.42 : 1 = 9.5 : 6.7.$$

The amount of heat, then, used in expanding the air — that is, in raising 2,160 pounds one foot high — is 2.8 units. Dividing 2,160 by 2.8, we get 772, nearly.

Since there is no cohesion among the particles of air, the whole expansive force is used in raising the weight.

We see, then, that 772 foot-pounds of mechanical force are equivalent to a unit of heat, and that a unit of heat is equivalent to 772 foot-pounds of mechanical force.

We have seen that merely to *melt* a pound of ice at a temperature of 32° Fahrenheit requires 143 units of heat, which is equivalent to the force required to lift 110,396 pounds, or about 55 tons, a foot high. And to convert a pound of boiling water into steam requires 967 units of heat, equivalent to the force required to lift 746,524 pounds, or about 373 tons, a foot high. The force of gravity is almost as nothing compared with this molecular force.

The strength of affinity is shown by the amount of heat developed by the combination of oxygen and hydrogen. It is found that, when oxygen unites with one pound of hydrogen, 61,000 units of heat are generated. Hence the force which has combined the two gases is equal to 61,000 × 772 = 47,092,000 foot-pounds, or the force necessary to raise 23,546 tons a foot high, or to throw one ton to a height of more than four miles. A pound of carbon, in combining with oxygen, gives out about 14,500 units of heat, equivalent to 11,194,000 foot-pounds. We see, then, that the force even of cohesion is insignificant compared with that of affinity.

8. *Energy may be transmuted, but not destroyed.* — We have now seen that mechanical motion may be converted into the molecular motions of heat and electricity, and that these molecular motions may be converted into mechanical motion.

Energy, like matter, may assume a great variety of forms; but, like matter, it is wholly indestructible.

9. *Source of Energy.* — If left to itself, affinity would soon bring all dissimilar atoms together, and lock them up in compounds; cohesion would bring all the molecules of these compounds together, and lock them up in solids; and gravity would bring all these solids together, and hold them in its iron grasp; while the heat developed by these forces would be radiated into space, and our earth become one dreary waste, void of all signs of life and activity. What, then, is the source of the energy which is thus manifesting itself in Protean forms?

Let us consider, first, the energy developed by gravity. This energy is seen in the winds, the falling rain, and running streams. The atmosphere on each side of the equator is an immense wheel. The side of this wheel next the equator is continually expanded, and thus made lighter, by the heat of the sun. Hence gravity pulls down the colder and heavier side in the polar regions, and thus the wheel is made to turn. Were it not for the sun's heat, it would soon come to rest.

Again, the heat of the sun evaporates the waters of the ocean, and in their gaseous state they are swept round with the atmospheric wheel till they come to colder regions, where they are condensed, and fall to the earth as rain, and flow to the ocean in rivers. It is due, then, to the heat which comes to the earth in the sunbeam, that gravity can thus unceasingly manifest its energy.

The energy of chemical affinity which is manifested in heat, light, and muscular force is developed by its action between oxygen and carbon. How are these elements separated from carbonic acid, so that they may be reunited by affinity?

Place a leafy plant in a glass vessel, and let a current of carbonic acid stream over it in the dark, and no change takes place. Let the same gas stream over the plant in the sunshine, and a part of it will disappear, and be replaced by oxygen. When acted upon by the sunbeams, leaves of plants remove carbonic acid from the air, separate its carbon and oxygen, retain the former, and give the latter back to the air. When plants are consumed by combustion in our furnaces, and by respiration in our bodies, this oxygen combines with carbon and develops energy, which appears as mechanical force in our engines, and as muscular force in our bodies.

In the summer, when more sunshine than we need is poured upon the earth, a part of it is absorbed by the leaves of plants, and used to decompose carbonic acid, to build up the varied forms of vegetable life. In this way, the forests and the fields become vast storehouses of force which has been gathered from the sunbeam. When, therefore, we burn fuel in our stoves and food in our bodies, the light, heat, and muscular force developed are only the reappearance in another form of the sunbeams stored up in plants.

But this process of gathering force from the sunlight has been going on for ages; and when we burn anthracite or bituminous coal, we are merely releasing the sunbeams imprisoned in plants which grew upon the earth before it became the dwelling-place of man.

The energy of affinity, then, like that of gravity, is nothing but transmuted sunshine.

The only form of energy known to us which does not come to the earth in the sunbeam is that developed by the ebb and flow of the tidal wave. This wave is dragged round the earth mainly by the attraction of the moon; and it acts as a brake upon the earth's rotation, since it is drawn from east to west while the earth is turning from west to east. The energy of this wave, then, is developed at the expense of the earth's motion on its axis; and it must tend to retard this motion, though to so slight a degree that the observations of thousands of years have not served to make it appreciable.

10. *The Amount of Heat given out by the Sun.* — Making allowance for the heat absorbed by the atmosphere, it has been calculated that the amount received by the earth during a year would be sufficient to melt a layer of ice 100 feet thick and covering the whole earth. But the sun radiates heat into space in every other direction as well as towards the earth; and if we conceive a hollow sphere to surround the sun at the distance of the earth, our planet would cover only $\frac{1}{2,300,000,000}$ of its surface. Hence the sun radiates into space 2,300,000,000 times as much heat as the earth receives. Sir John Herschel has calculated that if a cylinder of ice 45 miles thick were darted into the sun with the velocity of light (190,000 miles a second), it might be melted by the heat radiated by the sun, without lowering the temperature of the sun itself.

11. *Source of the Sun's Heat.* — It has been supposed by some that the materials of the sun are undergoing combustion, and that this combustion develops the light and heat which it sends forth. There are, however, no substances known to us whose burning would produce so much heat for so long a time as we know the sun has been shining. Carbon is one of the most combustible substances with which we are acquainted; but if the sun, large as he is, were a mass of pure carbon, and were burning at a rate sufficient to produce the light and heat that he is giving out, he would be utterly consumed in 5,000 years. It seems hardly possible, then, that the solar light and heat can be generated by ordinary combustion.

One of the most satisfactory theories of the origin of the solar heat is that developed in 1848 by a German physician, Mayer, and known as the *meteoric* theory.

We have seen that a pound-weight which has fallen through 772 feet will, when its motion is arrested, generate a unit of heat. Now, we know that a body falling that distance will acquire a velocity of about 223 feet a second. Hence a pound ball moving with a velocity of 223 feet a second will generate a unit of heat when its motion is arrested. We know, too, that the velocity with which a falling body strikes the ground is in proportion to the square root of the height from which it falls;

that is, in order to double or treble its velocity, a body must fall from four or nine times the height. A pound ball, then, moving with a velocity of twice 223 feet a second will be able to generate 4 units of heat; one moving with thrice this velocity, 9 units of heat; and so on. When, therefore, we know the weight of a body and the speed with which it is moving, we can easily calculate how much heat will be generated on stopping it.

Were the earth's motion arrested, its elements would melt with fervent heat, and most of them would be converted into vapor. Were the earth to fall into the sun, the heat generated by the shock would be sufficient to keep up the solar light and heat for 95 years. We know that countless swarms of meteoric bodies are revolving in rings about the sun, and that they must be moving in a resisting medium. If so, they must eventually be drawn into the sun, and, from the velocity with which they must strike, it has been shown that they could fall in sufficient numbers to generate all the light and heat of the sun, without increasing his magnitude enough to be detected, since accurate measures of his diameter were first made.

"Solar light and solar heat lie latent in the force which pulls an apple to the ground. The potential energy of gravitation was the original form of all the energy in the universe. As surely as the weights of a clock run down to their lowest position, from which they can never rise again unless fresh energy is communicated to them from some source not yet exhausted, so surely must planet after planet creep in, age by age, towards the sun. When each comes within a few hundred thousand miles of his surface, if he is still incandescent, it must be melted and driven into vapor by radiant heat. Nor, if he be crusted over and become dark and cool externally, can the doomed planet escape its fiery end. If it does not become incandescent, like a shooting-star, by friction in its passage through his atmosphere, its first graze on his surface must produce a stupendous flash of light and heat. It may be at once, or it may be after two or three bounds like a cannon-shot ricochetting on a surface of earth or water, the whole mass must be crushed, melted, and evaporated by a crash, generating in a moment some thousands of times as much heat as a coal of the same size would produce by burning." (Tyndall.)

12. *The Nebular Hypothesis.* — According to Laplace, the material of our solar system was once a nebulous mass of extreme tenuity, and the sun, moon, and planets were formed by its gradual condensation. Let us suppose such a nebulous mass slowly rotating, and gradually cooling by radiation into space. As it cools, it must begin to contract; and as it contracts, its rotation must be quickened, since the matter at the surface must be moving faster than nearer the centre. It thus goes on contracting and rotating faster and faster, until the centrifugal tendency becomes so great that cohesion and gravity can no longer hold it together. A ring is then detached from the circumference, which continues to rotate by itself. The central mass goes on contracting and rotating with ever-increasing velocity, until a second ring is thrown off. In this way, ring after ring is detached, and all these rings continue to rotate round the central mass in the same direction. But the rings themselves would go on condensing, and at last they would be likely to break up, each forming one or several globular masses. These would, of course, all revolve about the central mass in the same direction, and their condensation would cause them to rotate on their axes; and it has been proved that, with the exception of one or two of the outer ones, they must all rotate on their axes in the same direction in which they revolve in their orbits.

But as these masses condensed, their rotation would be accelerated, and they would be very likely to throw off rings, which would either remain as rings, or be condensed into globes.

The central mass, of course, forms the sun; the rings which it throws off, the planets; and the rings thrown off by the planets, the moons. In the case of Saturn, a part of the rings still remain uncondensed, while a part appear as moons.

The rings thrown off by the central mass usually condensed into one body, but, in the case of the minor planets and the meteoric rings, into many.

13. *Helmholtz's Theory of Solar Heat.* — Helmholtz has made the nebular hypothesis the basis of his theory of solar heat, an account of which is given by Tyndall as follows: —

"He starts from the nebular hypothesis of Laplace, and, assuming the nebulous matter in the first instance to have been of extreme tenuity, he determines the amount of heat generated by its condensation to the present solar system. Supposing the specific heat of the condensing mass to be the same as that of water, then the heat of condensation would be sufficient to raise their temperature 28,000,000° Centigrade. By far the greater part of this heat was wasted ages ago in space. . . . . Helmholtz supposes this condensation to continue ; that a virtual falling down of the superficial portions of the sun towards the centre still takes place, a continual development of heat being the result. However this may be, he shows by calculation that the shrinking of the sun's diameter by .0001 of its present length would generate an amount of heat competent to cover the solar emission for 2,000 years ; while the shrinking of the sun from its present mean density to that of the earth would have its equivalent in an amount of heat competent to cover the present solar emission for 17,000,000 of years.

"'But,' continues Helmholtz, 'though the store of our planetary system is so immense that it has not been sensibly diminished by the incessant emission which has gone on during the period of man's history, and though the time which must elapse before a sensible change in the condition of our planetary system can occur is totally beyond our comprehension, the inexorable laws of mechanics show that this store, which can only suffer loss and not gain, must finally be exhausted. Shall we terrify ourselves by this thought? We are in the habit of measuring the greatness of the universe, and the wisdom displayed in it, by the duration and the profit which it promises to our own race ; but the past history of the earth shows the insignificance of the interval during which man has had his dwelling here. What the museums of Europe show us of the remains of Egypt and Assyria we gaze upon with silent wonder, in despair of being able to carry back our thoughts to a period so remote. Still, the human race must have existed and multiplied for ages before the Pyramids could have been erected. We estimate the duration of human history at 6,000 years ; but, vast as this time may appear to us, what is it in comparison with the period during which the earth bore successive series of rank plants and mighty animals, but no men ? — periods during which, in our own neighborhood (Königsberg), the amber-tree bloomed, and dropped its costly gum on the earth and in the sea; when in Europe and North America groves of tropical palms flourished, in which gigantic lizards, and, after them, elephants, whose mighty remains are still buried in the earth, found a home. Different geologists, proceeding from different premises, have sought to estimate the length of the above period, and they set it down from one to nine millions of years. The time during which the earth has generated organic beings is again small compared with the ages during which the world was a mass of molten rocks. The experiments of Bischof upon basalt show that our globe would require 350 millions of years to cool down from 2,000° to 200° Centigrade. And with regard to the period during which the first nebulous masses condensed, to form our planetary system, conjecture must entirely cease. The history of man, therefore, is but a minute ripple in the infinite ocean of time. For a much longer period than that during which he has already occupied this world, the existence of a state of inorganic nature, favorable to man's continuance here, seems to be secured; so that for ourselves, and for long generations after us, we have nothing to fear. But the same forces of air and water, and of the volcanic interior, which produced former geologic revolutions, burying one series of living forms after another, still act upon the earth's crust. They, rather than those distant cosmical changes of which we have spoken, will put an end to the human race, and perhaps compel us to make way for new and more complete forms of life, as the lizard and the mammoth have given way to us and our contemporaries.'"

Mayer's theory is evidently not inconsistent with that of Helmholtz, but supplementary to it. The former merely assumes that the meteors and planets, which were thrown off from the nebulous mass as it condensed, are slowly falling into it again. When these shall all have fallen into it and the condensation shall have ceased, our sun will cease to shine, like many other stars which have disappeared from the heavens.

NOTES.

PART FIRST.

I.

ANOTHER way to find the specific gravity of a liquid is the following. Fill a small bottle accurately with water, and then with the liquid, and find the weight of each; then divide the weight of the liquid by the weight of the water, and the quotient will be the specific gravity required.

A *specific gravity bottle* is a bottle which is made to hold a definite weight of water, as 1,000 grains. If it holds 790 grains of alcohol, the specific gravity of the alcohol is evidently .79; if it holds 1,860 grains of sulphuric acid, the specific gravity of the acid is 1.86; and so on.

Again, since the weight which a body loses when immersed in a liquid is equal to the weight of its own bulk of that liquid (23), we can find the specific gravity of a liquid by dividing the weight which a body loses in that liquid by the weight which it loses in water. Thus, if a piece of copper loses 200 grains when weighed in water, and 158 grains when weighed in alcohol, the specific gravity of the alcohol is equal to 158 divided by 200, or .79.

II.

WHEN we know the velocity a body acquires in falling through a certain distance *a*, and we wish to know what velocity it will acquire in falling through any other distance *b*, divide the distance *b* by *a*, extract the square root of the quotient, and multiply the velocity the body acquires in falling through the distance *a* by the number thus obtained. If, on the other hand, we wish to know how far the body must fall to acquire any velocity *c*, divide the velocity *c* by the velocity a body acquires in falling through the distance *a*, square the quotient, and multiply the distance *a* by this number.

PROBLEMS.

1. A body in falling from a state of rest through 4.9 metres acquires a velocity of 9.8 metres. Through what distance must it fall to acquire a velocity of 39.2 metres?

2. To acquire a velocity of 88.2 metres?

3. To acquire a velocity of 125 metres?

4. To acquire a velocity of 396 metres?

5. What velocity does a body acquire in falling from a state of rest through 19.6 metres?

6. In falling through 44.1 metres?

7. In falling through 340 metres?

8. A body falls from a height of 60 metres. With what velocity does it reach the earth?

9. How long is the body in falling to the earth?

10. How long will it take a body to fall from a state of rest through 1,188 metres?

11. A cannon ball is fired horizontally from the top of a tower 60 metres high. How long will the ball remain in the air?

FRENCH WEIGHTS AND MEASURES.

☞ The English equivalents given below are those which were established by Congress, in July, 1866, and are sufficiently accurate for all practical purposes.

TABLE OF LINEAR MEASURE.

10 millimètres	= 1 centimètre	= 0.3937 inch.
10 centimètres	= 1 décimètre	= 3.937 "
10 décimètres	= 1 *mètre*	= 39.37 "
10 mètres	= 1 décamètre	= 393.7 "
10 décamètres	= 1 hectomètre	= 328 ft. 1 inch.
10 hectomètres	= 1 kilomètre	= 3280 " 10 "

TABLE OF MEASURES OF SURFACE.

100 centiares	= 1 *are*	= 119.6 square yards.
100 ares	= 1 hectare	= 2.471 acres.

The *centiare* is a *square mètre*, and is equal to 1,550 square inches.

TABLE OF MEASURES OF CAPACITY.

10 millilitres	= 1 centilitre	= 0.6102 cubic inches.		
10 centilitres	= 1 décilitre	= 6.1022	"	"
10 décilitres	= 1 *litre*	= 1.0567 wine quarts.		
10 litres	= 1 décalitre	= 2.6417	"	gallons.
10 décalitres	= 1 hectolitre	= 26.417	"	"
10 hectolitres	= 1 kilolitre	= 264.17	"	"

The *kilolitre* is a *cubic mètre*, and is also called a *stère*. The *décastère* = 10 stères.

TABLE OF WEIGHTS.

10 milligrammes	= 1 centigramme	= 0.1543 grains.	
10 centigrammes	= 1 décigramme	= 1.5432	"
10 décigrammes	= 1 *gramme*	= 15.432	"
10 grammes	= 1 décagramme	= 0.3527 oz. avoirdupois.	
10 décagrammes	= 1 hectogramme	= 3.5274 "	"
10 hectogrammes	= 1 kilogramme	= 2.2046 pounds	"

The *millier* or *tonneau* is equal to 1,000,000 grammes, or 2204.6 pounds avoirdupois.

NOTE. The names of the *higher* orders of units, or the *multiples* of the standard unit, are formed from the name of the *standard unit*, (the *mètre*, *litre*, etc.) by means of prefixes taken from the Greek numerals; namely, *déca-* (10), *hecto-* (100), *kilo-* (1,000).

The names of the *lower* orders of units, or the *subdivisions* of the standard unit, are formed in a similar manner by means of prefixes taken from the *Latin* numerals; namely, *déci-* (10), *centi-* (100), *milli-* (1,000).

PART SECOND.

1. (page 23.) For other methods of illustrating the formation of nodes see Tyndall's Lectures on "Sound."

2. (page 79.) *Sensitive Naked Flames.* — Professor Leconte of this country was the first to observe that ordinary gas-flames, even when not enclosed in tubes, are sensitive to sound. He gives the following account of his observations at a musical party: "Soon after the music commenced, I observed that the flame exhibited pulsations which were *exactly synchronous* with the audible beats. This phenomenon was very striking to every one in the room, and especially so when the strong notes of the violoncello came in. It was exceedingly interesting to observe how perfectly even the *trills* of this instrument were reflected on the sheet of flame. *A deaf man might have seen the harmony*. As the evening advanced, and the diminished consumption of gas in the city *increased the pressure*, the phenomenon became more conspicuous. The *jumping* of the flame gradually increased, became somewhat irregular, and, finally, it began to flare continuously, emitting the characteristic sound indicating the escape of a greater amount of gas than could be properly consumed. I then ascertained by experiment, that the phenomenon *did not* take place unless the discharge of gas was so regulated that the flame approximated to the condition of *flaring*. I likewise determined, by experiment, that the effects *were not* produced by jarring or shaking the floor and walls of the room by means of repeated concussions. Hence it is obvious that the pulsations of the flame *were not* owing to *indirect* vibrations propagated through the medium of the walls of the room to the burning apparatus, but must have been produced by the *direct* influence of aerial sonorous pulses on the burning jet." *

* Philosophical Magazine, March, 1858.

The significant remark, that the jumping of the flame was not observed until it was near flaring, suggests the means of repeating the experiments of Dr. Leconte; while a more intimate knowledge of the conditions of success enable us to vary and exalt them in a striking manner.

It will be noticed in the above account that the flame becomes more sensitive when it is near flaring.

Figure 238 represents the flame of a common fish-tail burner.

Fig. 238.

Fig. 239.

When this flame is not near flaring it is not at all sensitive to sound. If, however, we turn on the gas until the flame is on the point of flaring, and sound a whistle near it, the flame takes the form shown in Figure 239. With a bat's-wing burner the result is the same.

By using burners of suitable forms, flames may be obtained which are much more sensitive than ordinary gas-flames. The simplest burners, and those which show the sensitiveness of the flame best, can be made by drawing out small glass tubes into a fine jet.

Tyndall gives the following account of his experiments with a tall slender flame such as is shown in Figure 240: —

"The flame reaches a height of 24 inches. The slightest tap on a distant anvil reduces its height to 7 inches. When I shake this bunch of keys the flame is violently agitated, and emits a loud roar. The dropping of a sixpence into a hand already containing coin, at a distance of 20 yards, knocks the flame down. I cannot walk across the floor without agitating the flame. The creaking of my boots sets it in violent commotion. The crumpling or tearing of a bit of paper, or the rustle of a silk dress, does the same. It is startled by the patter of a rain-drop. I hold a watch near the flame; nobody hears its ticks; but you all see their effect upon the flame. At every tick it falls. The winding up of the watch also produces tumult. The twitter of a distant sparrow shakes the flame down; the note of a cricket would do the same. From a distance of 30 yards I have chirruped to this flame, and caused it to fall and roar. I repeat a passage from Spenser: —

Fig. 240.

'Her ivory forehead, full of bounty brave,
  Like a broad table did itself dispread,
For Love his lofty triumphs to engrave,
  And write the battles of his great godhead.
All truth and goodness might therein be read,
  For there their dwelling was, and when she spake,
Sweet words, like dropping honey she did shed;
  And through the pearls and rubies softly brake
A silver sound, which heavenly music seemed to make.'

Fig. 241.

The flame picks out certain sounds from my utterance; it notices some by the slightest nod, to others it bows more distinctly, to some its obeisance is very profound, while to many sounds it turns an entirely deaf ear.

"In Figure 240 this tall, straight, and brilliant flame is represented. On chirruping to it, or on shaking a bunch of keys within a few yards of it, it falls to the size shown in Figure 241, the whole length, *a b*, of the flame being suddenly abolished. The light at the same time is practically destroyed, a pale and almost non-luminous residue of it alone remaining.

"We have called this the *vowel flame*, because the different vowel sounds affect it differently. We have already learned how these sounds are formed; that they differ from each other through the admixture of higher tones with the fundamental one. It is to these tones, and not to the fundamental one, that our flame is sensitive. I utter a loud and sonorous U, the flame remains steady; I change the sound to O, the flame quivers; I sound E, and now the flame is strongly affected. I utter the words *boot*, *boat*, and *beat* in succession. To the first there is no response; to the second, the flame starts; but by the third it is thrown into greater commotion; the sound *Ah!* is still more powerful. Did we not know the constitution of vowel sounds this deportment would be an insoluble enigma. As it is, however, the flame is a demonstrator of the theory of vowel sounds. It is most sensitive to sounds of high pitch; hence we should infer that the sound *Ah!* contains higher notes than the sound E; that E contains higher notes than O; and O higher notes than U. I need not say that this agrees perfectly with the analysis of Helmholtz.

"This flame is peculiarly sensitive to the utterance of the letter S. If the most distant person in the room were to favor me with a hiss, the flame would instantly sympathize with him. A hiss contains the elements that most forcibly affect this flame. The gas issues from its burner with a hiss, and an external sound of this character is therefore exceedingly effective. I hold in my hand a metal box, containing compressed air. I turn the cock for a moment, so as to allow a puff to escape, — the flame instantly ducks down, not by any transfer of air from the box to the flame, for I stand at a distance which utterly excludes this idea; it is the *sound* that affects the flame. I send a man to the most distant part of the gallery, where he permits the compressed air to issue in puffs from the box; at every puff the flame suddenly falls. Thus the hiss of the issuing air at the one orifice precipitates the tumult of the flame at the other.

"Finally, I place this musical box upon the table, and permit it to play. The flame behaves like a sentient creature; bowing slightly to some tones, but courtesying deeply to others."

What now is the explanation of these phenomena?

If we use a burner with a single circular orifice of such a size that it requires a great pressure to make the flame flare, we may, by turning on the gas, obtain a flame 15 or 20 inches long. If we make it longer and larger, it will at length begin to quiver and finally to flare, shortening considerably at the same time. If we diminish the pressure a little, so as to bring the flame just below its point of flaring, it shortens on sounding a whistle near it, exactly as it did when the pressure was increased. Like the singing flame which was started by the voice (78), it stands on the brink of a precipice, and the proper sound pushes it over. We see, then, that the effect of sound upon a naked flame is the same as that of an increase in the pressure of the gas. The gas in escaping from the orifice of the burner encounters friction, and when the pressure of the gas is sufficient, the stream as it issues is thrown into vibration. It is this vibration which causes the flame to flare. Sonorous pulses of the proper period may also throw the stream of gas into vibration, and thus cause the flame to flare. In a word, then, the flame flares because the gas as it escapes from the burner is thrown into vibration, and it may thus be thrown into vibration by increasing the pressure of the gas or by the action of sonorous pulses of the proper period.

It has been found that liquid jets, as well as gas jets, are sensitive to sound.

3. (page 101.) Total reflection in a liquid may be elegantly illustrated by the following experiment. Near the bottom of a tall vessel a round hole is made for water to run out; opposite this hole is a glass plate, through which a beam of solar or electric light is admitted. The vessel is filled with water, and the outlet opened. The beam of light is totally reflected from the inner surfaces of the liquid jet, and is therefore carried down with it, lighting it up throughout its whole extent. To produce the best effect the vessel should be set high enough to give a jet of considerable length.

4. (page 116.) M. Plateau gives the following directions for preparing the liquid for these soap-bubbles: 1. Dissolve one part *by weight* of white soap, cut into thin slices, in forty parts

of distilled water, and filter. 2. Mix two parts *by measure* of pure glycerine with one part of the filtered solution, in a temperature of 66° F., and, after shaking them together long and violently, leave them at rest for some days. A clear liquid will settle, with a turbid one above. The lower is to be sucked out from beneath the upper with a siphon, taking the utmost care not to carry down any of the latter to mix with the clear liquid. A bubble blown with this will last several hours in the open air. Or, the mixed liquid, after standing twenty-four hours, may be filtered.

5. (page 126.) The simplest and most satisfactory way of seeing diffraction fringes is to place wire gauze of various coarseness over the object-glass of an ordinary telescope, and then to look at some brilliant point of light, as a star, or the image of the sun reflected from a flask filled with water. The fringes will vary with the coarseness of the gauze used. They may be seen even when the meshes are a quarter of an inch across. The experiment is very easy and is well worth trying.

6. (page 195.) The laws of the reflection and refraction of luminous and obscure heat are best illustrated with the lime light and the iodine cell. Let the light pass through the largest aperture of the diaphragm, and concentrate it by a lens. Let the pencil thus concentrated fall upon the small mirror placed so near that it is not brought to a focus till after reflection. Place the blackened bulb of a differential thermometer at this focus, and the reflection of the luminous heat is proved. Place the iodine cell behind the lens so as to cut off all luminous radiation, and again place the bulb of the thermometer at the focus previously marked, and the reflection of the obscure heat is proved. For refraction, use the refracting prism instead of the mirror, placed so near that the light is not brought to a focus till after refraction. Of course it is easy to form invisible foci with any lens or concave mirror. These experiments are in every way satisfactory. Care must be taken in using the iodine solution, as it is very inflammable. After use it should be removed from the cell and kept in a well-corked bottle.

7. (page 271.) The zinc used for battery purposes should in all cases be amalgamated. This may be done either by immersing the zinc in mercury, or by rubbing its surface with that metal. In either case the zinc should first be cleaned with dilute sulphuric acid.

It is well to amalgamate the zinc plates of a battery every time it is used, and the best time for doing this is when the battery is taken down after being used, as the zincs then need no cleaning. For amalgamating the zincs of a large Bunsen's battery, a cylindrical vessel of soapstone, made with a core and just large enough for immersing the zincs in the mercury, will be found convenient. With such a vessel, not more than forty pounds of mercury will be needed. After immersion in the mercury the zincs should be set to drain in an iron sink, the surplus mercury being caught in a vessel below.

8. (page 300.) Here, as elsewhere, we have described only one or two experiments, which serve to illustrate the principles. If the teacher has the apparatus for a larger number of experiments, he will of course make use of it at the proper point; if he has not, it is hardly worth while that the pupil should learn descriptions of experiments which he never witnesses.

A very pleasing illustration of the electric light in rarefied air is afforded by the "guinea and feather tube" used in pneumatic experiments. If the ends of the tube are connected with the poles of the inductorium (or with the electrical machine) purple flashes of auroral light mark the passage of the current through the tube when the air is exhausted. In all experiments of this kind, the room should be darkened.

Gassiot's cascade is a simple and inexpensive piece of apparatus for showing the electric light in a vacuum. It consists of a large glass goblet (uranium glass is best), the inside of which is coated nearly to the top with tinfoil. Place the vessel on the plate of the air-pump, cover it with a receiver which has a sliding rod through the top, bring the sliding rod in contact with the tinfoil coating, and connect one pole of the inductorium (or one conductor of the electrical machine) with the rod, and the other with the pump-plate. When the air is exhausted. and the current sent through the receiver, streams of blue light flow from the tinfoil over the side of the vessel to the pump-plate. A variety of beautiful effects are produced by different degrees of exhaustion, and by changing the direction of the current.

The apparatus known as the *Abbé Nollet's Globe* also furnishes very pretty displays of the electric light in rarefied air. It consists of a glass globe suspended in the upper part of a glass bell-jar, and arranged so that it can be partially filled with water, and connected with the inductorium or the electrical machine by means of a chain dipping into the water. The light in this case flows in lambent streams from the globe to the pump-plate.

A variety of pieces of apparatus for showing the electric light are made by pasting bits of tinfoil about $\frac{1}{20}$ of an inch apart on glass, oiled silk, or other non-conducting substance. Letters, outline figures, etc., may thus be formed, which appear in lines of scintillating light when the current is sent through them.

The pieces of tinfoil may be pasted in a spiral on the inside of a long glass tube, and lighted up in the same way.

The *diamond jar*, as it is sometimes called, is a Leyden jar, the coatings of which are composed of small pieces of tinfoil, separated from one another. Brilliant sparks pass between these pieces when the jar is charged or discharged.

If the knob of a common Leyden jar is connected with one pole of the inductorium, and a wire from the other pole is brought near the outer coating of the jar, bright sparks pass in most rapid succession between the pole and the jar. The electrical machine may be used instead of the inductorium in this experiment, but the effect is much less striking.

The teacher will find many other experiments in the works on Electricity mentioned in the Preface, especially in the little book of Ferguson's. To those who have Ruhmkorff's coil, we commend a little volume by Noad, entitled "The Inductorium," (London, John Churchill and Sons, 1866) which describes a large number of beautiful and instructive experiments with that instrument.

QUESTIONS FOR REVIEW AND EXAMINATION.

PART FIRST.

1. WHAT is true of the parts of a stone or a piece of wood? 2. What are such bodies called? 3. When is a body called a solid? 4. What substances are called liquids? 3. Give an illustration. 6. Show that a vessel cannot be filled with water until the air is removed from it. 7. What are substances like air called? 8. How many states of matter are there? 9. What are they called? 10. Show that there is a force drawing bodies toward the earth. 11. What is this force called? 12. What is weight? 13. Show that all bodies do not have the same weight. 14. How can we find how much heavier one body is than another? 15. Describe the spring balance. 16. Explain how bodies may be weighed by it. 17. Show how we can find the weight of bodies by means of a rod poised at its centre. 18. Describe the balance. 19. Show how we can find the weight of a body by means of a rod poised at a point near one of its ends. 20. Describe the steelyard. 21. When a rod is alike throughout its whole length, where must it be supported in order to have the force of gravity acting upon one arm balance that acting upon the other? 22. When a weight is hung to one end of the arm just twice as heavy as that hung to the other, where must the rod be supported in order to have the force of gravity acting upon one arm just balance that acting upon the other? 23. What is true of a disc of wood when supported at its centre? 24. What is true of the same disc when one side of it is loaded with lead? 25. What point may be found for every body? 26. What is this point called? 27. Define the centre of gravity of a body. 28. Show that the centre of gravity is not always in the body itself. 29. What is true of the centre of gravity of two balls connected by a rod? 30. When a loaded disc which is supported at its centre is

placed in different positions, what is true of it? 31. When is a body said to be in equilibrium? 32. When, in stable equilibrium? 33. When, in unstable equilibrium? 34. When, in indifferent equilibrium? 35. Show that the centre of gravity seeks the lowest point it can reach. 36. Illustrate the different kinds of equilibrium by means of spheres. 37. What is true of the centre of gravity in each kind of equilibrium? 38. Show that the broader the base of a body compared with its height, the greater the stability of its equilibrium. 39. Show that a body with a broad base may be in unstable equilibrium. 40. When may a leaning body be in stable equilibrium? 41. Show that a body having a very narrow base may be in stable equilibrium. 42. Show how the centre of gravity of a body may be found. 43. How do we know that liquids have weight? 44. Are all liquids equally heavy? 45. Show that liquids when acted upon by gravity press not only downward, but also upward and sideways. 46. Show that the upward, downward, and lateral pressures are equal for the same depth of liquid. 47. Show that these pressures increase with the depth. 48. Show that these pressures do not depend at all upon the form or size of the vessel which holds the liquid. 49. Show what takes place when different vessels are connected, and one of them filled with a liquid. 50. Show that a pressure of $\frac{1}{50}$ of a pound upon a particle of water in a closed vessel causes every particle of water at the surface to exert an upward pressure of $\frac{1}{50}$ of a pound. 51. Show that a pressure of $\frac{1}{50}$ of a pound upon a particle of water in a closed vessel causes the particles of different depths to exert the same upward pressure as those at the surface. 52. Show that when any pressure is brought to bear upon any particle of a liquid, each particle is made to exert the same pressure upward, downward, and sideways. 53. What is true when any pressure is brought to bear upon any particle of a liquid in a closed vessel? 54. How by means of a liquid may a small pressure be made to exert a great one? 55. Describe the hydrostatic press, and explain its action. 56. What do all natural collections of water illustrate? 57. Give an example. 58. Explain the formation of springs. 59. Why are Artesian wells so named? 60. Explain their action. 61. What is true of a body when placed in water?

62. Show this. 63. How much is a body buoyed up in water? 64. Show this. 65. When will a body sink in water? 66. When float? 67. When a body floats in a liquid, how much of the liquid does it displace? 68. Why do iron ships float? 69. When is one body said to be more dense than another? 70. What is specific gravity? 71. What must be known to find the specific gravity of a solid or liquid? 72. How can we find the weight of a bulk of water equal to that of a solid? 73. Describe the hydrometer in Figure 23, and show how the specific gravity of a liquid is found by means of it. 74. Describe the hydrometer in Figure 24, and explain how it is used in finding the specific gravity of a liquid. 75. Show that gases have weight. 76. How do gases press? 77. Show that they press in this way. 78. Tell what you can about the hand-glass. 79. About the Magdeburg hemispheres. 80. About the weight-lifter. 81. Show that gases have an expansive force. 82. Describe the air-pump, and explain its action. 83. Show that a body is buoyed up in the air. 84. When will a body rise in the air? 85. When will it sink in the air? 86. Why do balloons rise? 87. With what must they be filled? 88. How are paper balloons sometimes made to rise? 89. Show that the atmospheric pressure will hold up a column of liquid in an inverted vessel. 90. How high a column of mercury will the atmospheric pressure hold up in a tube? 91. Show this. 92. The atmospheric pressure is equal to how many pounds to the square inch? 93. Show this. 94. Show what is true of the atmospheric pressure from day to day. 95. Show what is true of the atmospheric pressure as we go away from the earth. 96. Describe the barometer. 97. Give an account of its uses. 98. How high a column of water will the pressure of the atmosphere sustain? 99. How do we know? 100. What is a pump? 101. Describe the lifting pump, and explain its action. 102. Describe the force-pump. 103. What pumps are there in the fire-engine? 104. What is a siphon? 105. Explain the action of a siphon. 106. Explain Tantalus's Cup. 107. Explain intermittent springs. 108. What increases the expansive force of gases? 109. Explain the air-gun. 110. Describe the condenser. 111. State Mariotte's law. 112. Illustrate this law. 113. What is a manometer? 114. Describe a manometer.

115. Describe the spirit-level, and explain its use. 116. Show that gravity may put a body in motion, as well as cause it to exert pressure. 117. Will a body begin to move or come to rest of itself? 118. State the first law of motion. 119. How do we know that a body will move in this way? 120. Show that an unbalanced force must act upon a body in order to put it in motion. 121. What is necessary to change the speed or direction of a moving body? 122. Why does it seem to us more natural for a body to be at rest than in motion? 123. What is the effect of a force acting upon a body for a moment only? 124. What is the effect of a force acting upon a body continuously? 125. Show that the resistance a body meets increases as the square of its velocity. 126. Show that a moving body may be in equilibrium. 127. State the second law of motion. 128. Illustrate this law in the case of a body thrown forward. 129. In the case of a body thrown upward. 130. In the case of a body thrown downward. 131. When does a moving body acted upon by gravity describe a curved path? 132. Illustrate this. 133. What is true of the speed with which all bodies would fall were it not for the air? 134. Show that this is so. 135. At what rate does gravity increase the speed of a body falling directly downward? 136. Show that this is so. 137. Show how we find the distance a body falls in a given time. 138. Show at what rate gravity retards the velocity of a body moving directly upward. 139. Show how we find the distance a body rises in a given time. 140. What is true of the velocity a body always acquires in falling the same distance? 141. Show that this is so. 142. Through what distance must a body fall, in order to double its velocity? 143. With how many times greater velocity must a body start, in order to rise to double the height? 144. How does the velocity which a falling body acquires compare with the height from which it falls. 145. How does the height to which a body will rise compare with the velocity with which it starts? 146. Show that the same force acting upon different quantities of matter does not impart to them the same velocity. 147. What do we mean by the mass of a body? 148. By its momentum? 149. Does the same force always give the same momentum to a body, whether it be great or small? 150. State

the third law of motion, or the law of action and reaction. 151. Illustrate this law by means of lead and ivory balls. 152. From what does this law result? 153. What is usually said of a force which acts in opposite directions? 154. Give some illustration of this. 155. Give some illustration of the fact that it requires time to transmit motion from particle to particle of a body. 156. What are the two effects when a body is met by a body in motion? 157. How does the power of a body to pierce another increase? 158. Give an illustration of reflected motion. 159. Show what is meant by the angle of incidence and that of reflection. 160. State the law of reflected motion. 161. What is a pendulum? 162. Explain the vibration of a pendulum. 163. How many kinds of pendulum are there? 164. Illustrate the first law of the pendulum. 165. State this law. 166. Illustrate the second law of the pendulum. 167. State this law. 168. Illustrate the third law of the pendulum. 169. State this law. 170. State and illustrate the fourth law of the pendulum. 171. Describe the compound pendulum. 172. Show how the particles of a compound pendulum affect one another's movements? 173. What is the centre of vibration of a compound pendulum? 174. What is the virtual length of a compound pendulum? 175. Show what is true of the centres of vibration and of suspension? 176. What is a common clock? 177. Describe the action of the escapement. 178. To what is the second-hand of a clock attached? 179. What carries the minute-hand? 180. What carries the hour-hand? 181. What puts the clock in motion? 182. What regulates the motion of the clock? 183. How is the pendulum kept vibrating? 184. Show how the pendulum is used for measuring the force of gravity. 185. Explain how a workman raises a heavy stone. 186. What is the bar he uses called? 187. What is the stone to be raised called? 188. What is the moving force applied to the end of the bar called? 189. What is the block upon which the bar rests called? 190. Give an illustration of a lever in which the power is applied between the weight and fulcrum. 191. How many kinds of lever are there? 192. In what respect do they differ? 193. State the law of the lever, and show its truth by an illustration. 194. What is the law of every machine, however complicated? 195. When is there said to be a gain of power in a machine? 196. When, a loss of power? 197. When there is a gain in power, there is always a loss in what? 198. When there is loss in power, there is always gain in what? 199. What is true of the gain or loss of power in a lever of the first kind? 200. In a lever of the second kind? 201. In a lever of the third kind? 202. Explain the compound lever shown in Figure 54. 203. Give an illustration of a bent lever. 204. What are the lengths of the arms of a bent lever? 205. Why cannot a lever be conveniently used when a weight is to be raised a considerable distance? 206. Describe the rack and pinion. 207. How does the rack and pinion answer to the lever? 208. Describe the windlass. 209. How does this differ from the rack and pinion? 210. How may the gain of power in the windlass be increased? 211. Describe the capstan. 212. How may the windlass be converted into a wheel and axle? 213. How may the power be applied to the wheel? 214. How may the law of machines be illustrated by means of the wheel and axle? 215. Describe the ratchet. 216. Why may not the power of a wheel and axle be increased to any extent? 217. Show how several wheels may be combined so as to increase the power of this machine? 218. What are cog wheels? 219. Explain the gain of power in the wheel-work shown in Figure 60. 220. What are spur-wheels? 221. Crown-wheels? 222. Bevel-wheels? 223. What are belted wheels? 224. What are some of the advantages of belted wheels over cog wheels? 225. Show how the direction of the power may be changed by means of a rope. 226. What is a pulley? 227. What is a fixed pulley? 228. What is a movable pulley? 229. State the law of the pulley. 230. Apply this law to the systems of pulleys with one rope shown in Figures 65 and 66, and show what weight will be balanced by a power of one pound in each case. 231. Apply the same law to the system of pulleys with more than one rope, shown in Figures 67 and 68, and show what weight will be balanced by a power of one pound in each case. 232. Give an illustration of an inclined plane. 233. What is the height of an inclined plane? 234. What is the length of an inclined plane? 235. Show that the law of the inclined plane is the same as that of other machines. 236. What is a wedge?

237. What are its chief uses? 238. What is a screw? 239. What is the nut? 240. What is the inclined surface of the screw called? 241. Show how the mechanical advantage of the screw may be increased. 242. Describe Hunter's Screw, and explain its action. 243. Describe the endless screw. 244. What is the first source of mechanical power mentioned? 245. What are hand machines? 246. Give some illustration of hand machines. 247. Describe the crab. 248. Describe the derrick. 249. What is the second source of mechanical power mentioned? 250. What are horse-powers? 251. Show how a horse may be made to raise weights by means of pulleys. 252. How can a horse be made to turn an upright shaft? 253. Show how a horse may be made to move an endless platform, and thus to work machinery. 254. By what power are ships sometimes driven? 255. Describe a windmill. 256. What is true of water as a source of mechanical power? 257. What is a water wheel? 258. When are water wheels called vertical, and when horizontal wheels? 259. Describe the breast-wheel, 260. The overshot wheel. 261. The undershot wheel. 262. Describe Barker's mill, and explain its action. 263. What form of the arms is found to give the greatest power to Barker's mill? 264. Why? 265. What would be the effect of increasing the number of the arms in this machine? 266. Describe the turbine wheel. 267. Describe Marcet's globe. 268. What is shown by means of this globe? 269. How? 270. What is a steam engine? 271. Show how the elastic force of steam can be made to work a piston. 272. Show how the motion of the piston-rod may be made to turn a crank. 273. Describe the engine shown in Figure 89. 274. Explain the action and use of the governor. 275. Explain the use of the fly-wheel. 276. Explain the difference between a high and a low pressure engine. 277. What must the boiler be capable of doing? 278. Of what are boilers usually made? 279. Describe the Cornish boiler. 280. Describe the boiler shown in Figures 91 and 92. 281. Describe the boiler of a locomotive engine. 282. Describe the locomotive engine.

QUESTIONS FOR REVIEW AND EXAMINATION.

PART SECOND.

SOUND.

1. What is the condition of a sounding body? 2. Show this. 3. Can sound traverse a vacuum? 4. Show this. 5. Can sound pass through gases? 6. Show this. 7. Can it pass through solids and liquids? 8. Show this. 9. How is sound propagated? 10. Explain this propagation. 11. Upon what does the intensity of sound depend? 12. Show this. 13. At what rate does the intensity of the sound diminish with the distance? 14. Illustrate this. 15. Explain the use of speaking-tubes. 16. What is the velocity of sound in air? 17. Explain how this velocity was found. 18. What is the computed velocity of sound in air? 19. Explain the disagreement between this and the observed velocity. 20. Upon what does the velocity of sound in any medium depend? 21. Does the velocity of sound vary with the elevation of the place? 22. Why is this so? 23. What is the velocity of sound in water? 24. How was this found? 25. How does the velocity of sound in air compare with its velocity in solids? 26. Illustrate, by means of ivory balls, the transmission of the vibration of sound from particle to particle, and show what takes place when the sound-wave meets a new medium. 27. What is true of the angles of incidence and reflection? 28. Show this. 29. Explain echoes. 30. Give an account of some remarkable echoes. 31. What takes place when a sound-wave passes obliquely into a new medium? 32. Explain this fully, and give an illustration. 33. What is the difference between a musical sound and a noise? 34. Give an illustration of a musical sound, and show upon what its pitch depends. 35. Describe the tuning-fork. 36. Describe the siren. 37. Explain how the rate of a body's vibration may be found. 38. Show how to find the length of a

sound-wave. 39. When do sounds differ by an octave? 40. Describe the sonometer. 41. What effect has the length of a string upon the rapidity of its vibration? 42. Show this. 43. Illustrate the formation of nodes by means of the sonometer. 44. Show that nodes may be formed in vibrating plates. 45. What is meant by the fundamental tone of a body? 46. By its overtones or harmonics? 47. To what is the quality of sound due? 48. What does Tyndall propose to call the quality of sound? 49. Show that musical sounds can be transmitted through liquids. 50. Give Tyndall's illustration of the transmission of musical sounds through solids. 51. Wheatstone's illustration of the same. 52. What are sympathetic vibrations? 53. Illustrate these vibrations by means of the sonometer. 54. By means of tuning-forks. 55. By means of clocks. 56. Describe the super-position of water-waves. 57. What is the law of this mingling of the waves? 58. Show that a great variety of sound-waves may traverse the air together. 59. When are sound-waves said to interfere? 60. Illustrate this interference by means of a long bent tube. 61. By means of a vibrating plate. 62. By means of a tuning-fork. 63 What are beats? 64. Illustrate their formation by means of tuning-forks. 65. To what is their number per second equal? 66. Illustrate beats by means of organ-pipes. 67. By means of sounding flames. 68. Give Tyndall's illustration of resultant tones. 69. Illustrate these tones by means of the siren, and show to what rate of vibration their pitch answers. 70. What was Young's explanation of resultant tones? 71. Why is this explanation unsatisfactory? 72. Give Helmholtz's explanation. 73. What are difference tones and summation tones? 74. When are two musical sounds in unison? 75. When do they form an octave? 76. When a fifth? 77. When a fourth? 78. When a major third? 79. When a minor third? 80. What is a chord? 81. What is a discord? 82. Which chords are most agreeable? 83. Give Euler's explanation of chords and discords. 84. State the objections to this explanation. 85. Give Tyndall's illustration of Helmholtz's explanation of discord. 86. State Helmholtz's theory. 87. Are those combinations of notes which are actually found to be agreeable and disagreeable fully explained by this theory? 88. Show this. 89. Give an account of the musical scale. 90. What are stringed instruments? 91. Show that a string vibrating alone gives only a feeble sound. 92. Illustrate the use of a sounding-board. 93. State the laws of the vibration of strings, and illustrate each. 94. Illustrate the longitudinal vibration of a wire. 95. Show that the longitudinal vibration of a wire grows more rapid as the wire is shortened. 96. Show that the rapidity of these vibrations is independent of the tension of the wire. 97. Show how to find the relative velocity of sound in wires of different material. 98. Give an account of the longitudinal vibration of rods free at one end. 99. Illustrate the longitudinal vibration of a rod free at both ends. 100. Illustrate the lengthening and shortening of the halves of such a rod. 101. Show how to find the relative velocity of sound in different solids. 102. Illustrate resonance. 103. What is the length of a column of air which resounds to any tuning-fork? 104. Show this. 105. Explain resonance. 106. Give Savart's illustration of resonance. 107. Give some further illustrations of resonance. 108. Show that a column of air in a tube has power to select and reinforce particular sounds. 109. Explain what takes place on blowing across the mouth of a tube. 110. Show at what rate the vibration of a column of air in a tube varies with its length. 111. What are stopped and what open tubes? 112. How do the notes given by a stopped and by an open tube compare? 113. What are organ-pipes? 114. Explain how they are made to speak. 115. Show how the condition of the air within an open pipe may be examined by means of a stretched membrane. 116. What is the condition of this air found to be? 117. Show how the condition of the air inside an organ-pipe may be examined by means of gas-jets. 118. Why does an open pipe give the octave of a closed pipe of the same length? 119. Show how to find the relative velocity of sound in different gases. 120. In different liquids. 121. Show how to find the real velocity of sound in different substances. 122. What are reed pipes? 123. Explain the action of the reed. 124. When is the sound of the reed pipe most pure and forcible? 125. Illustrate the action of a reed by means of a straw. 126. Give some illustrations of reed instruments. 127. What are the two classes of wind instruments?

128. What is always true of friction? 129. Give some illustrations. 130. How may the noise of a gas-flame be converted into a musical note? 131. Show upon what the pitch of a sounding flame depends. 132. Show that a sounding flame is alternately extinguished and relighted. 133. Does the pitch of a sounding flame depend at all upon the size of the flame? 134. Show this. 135. Give some account of sensitive flames within tubes. 136. Describe the organs of the human voice, and illustrate their action. 137. Explain the formation of vowel sounds. 138. Describe the human ear. 139. Give an account of the range of the human ear.

LIGHT.

140. Define a luminous and a non-luminous body. 141. Show that a luminous body sends out light in every direction. 142. Define transparent and opaque bodies. 143. Show that light traverses space in straight lines, and explain the formation of shadows. 144. Define a ray, a pencil, and a beam of light. 145. Find the velocity of light. 146. At what rate does the intensity of light diminish with the distance? Show this. 147. What is a photometer? 148. Describe Count Rumford's photometer. 149. What happens when light meets a new medium? Illustrate. 150. State and illustrate the law of reflection. 151. Upon what does the intensity of reflected light depend? Illustrate. 152. When is light said to be diffused? 153. State and illustrate the law of refraction. 154. What is the index of refraction? 155. Explain total reflection. 156. Explain mirage. 157. Mention and explain other effects of refraction. 158. Show the path of the rays through a medium with parallel faces. 159. Through a prism. 160. Illustrate dispersion. 161. Explain the achromatic prism. 162. Show that the prismatic colors are simple and unequally refrangible. 163. Illustrate the composition of white light. 164. What three colors will produce white light by their mixture? 165. Why cannot the spectrum be made up of red, yellow, and blue? 166. When are colors said to be complementary? 167. Illustrate absorption. 168. Explain the color of bodies. 169. Show

how to analyze the color of bodies. 170. Show that different substances give flames of different colors. 171. Describe the spectroscope, and explain its use. 172. Show that gases absorb the same kind of light that they emit when incandescent. 173. What are Fraunhofer's lines? 174. Account for their presence in the spectrum of sunlight and starlight. 175. Describe the colors of the soap-bubble. 176. Show that these colors are independent of the liquid of which the bubble is made. 177. Show to what these colors are due. 178. Why do we suppose that light is transmitted by vibrations? 179. Why is the bubble black at the top just before it bursts? 180. Illustrate the change of the phase of the wave when reflected from the surface of a rarer medium. 181. Find the distance between the reflecting surfaces at the different colored rings. 182. What is the ether? 183. Find the length of the light-waves for the different colors. 184. What is the origin of light? 185. Why do different substances emit light of different colors? 186. Why do different substances absorb light of different colors? 187. Illustrate diffraction fringes. 188. Explain the formation of these fringes. 189. Show the action of Iceland spar upon light. 190. Describe the double-refracting prism. 191. Show that the ordinary and extraordinary rays are both polarized. 192. Explain polarization and double refraction. 193. Show the action of tourmaline upon ordinary light. 194. Show that light may be polarized by reflection and by refraction. 195. Define a polarizer and an analyzer. 196. Describe a Nicol's prism, and explain its action. 197. Show that polarized light can interfere only when the rays are polarized in the same plane. 198. Explain circular and elliptical polarization. 199. Illustrate and explain rotatory polarization. 200. Explain the colors seen in crystalline plates by polarized light. 201. Mention other phenomena of polarized light. 202. Describe the tourmaline pincette. 203. Explain the rainbow. 204. Describe the different kinds of lenses. 205. Explain the action of the double-convex lens. 206. Explain the formation of images by lenses. 207. Describe the camera obscura. 208. Describe the eye. 209. Explain the adjustment of the eye. 210. Describe the retina. 211. Explain the action of light upon the optic nerve. 212. Show that the sensation of light may be produced by other causes than light itself. 213. Illustrate the duration of the impression of light upon the retina. 214. Describe and explain the thaumatrope. 215. What is irradiation? Illustrate. 216. Show that the sensibility of the retina is easily exhausted. 217. What is color-blindness? 218. Explain single vision. 219. Define optical axis and visual angle. 220. How do we estimate the size of an object? 221. Show how we estimate the distance of an object. 222. Why do near bodies appear solid? 223. Describe the stereoscope. 224. State and illustrate the laws of distinct vision. 225. Describe the simple microscope. 226. The compound microscope. 227. The telescope. 228. The terrestrial telescope. 229. The opera-glass. 230. The magic lantern. 231. The solar microscope. 232. Explain the action of plane mirrors upon light. 233. Explain the formation of multiple images by plane mirrors. 234. Explain the action of concave mirrors upon parallel and upon divergent rays. 235. Explain the formation of images by concave mirrors. 236. Explain the action of convex mirrors upon parallel and divergent rays. 237. Describe the reflecting telescope. 238. Explain the action of parabolic mirrors. 239. Illustrate the chemical action of light. 240. Give an account of the daguerreotype process. 241. Of the collodion process. 242. Of photographic printing. 243. Show the chemical action of the solar spectrum.

HEAT.

244. Show that heat is radiated in all directions. 245. Show that heat traverses space in straight lines, and with the velocity of light. 246. Define luminous and obscure heat. 247. Define diathermancy. 248. Show that heat is reflected in the same way as light. 249. That it is refracted like light. 250. That it is dispersed like light. 251. That heat and light are one and the same. 252. Find the proportion of obscure and luminous radiation in the electric light, and in sunlight. 253. Show that the obscure radiation increases in intensity with the temperature. 254. What are invisible foci, and how may they be formed? 255. Explain calorescence, fluorescence, and phos-

phorescence. 256. Show that different solids and liquids absorb the same kind of heat differently. 257. Show that the same solid absorbs different kinds of heat differently. 258. What is meant by the quality of heat? 259. Show that different gases absorb the same quality of heat differently. 260. Show that the same gas absorbs different qualities of heat differently. 261. Show that vapors absorb the same quality of heat in the same order as their liquids. 262. Show that good absorbers are good radiators. 263. Show how bodies radiate and absorb heat. 264. Show upon what the absorptive power of bodies depends. 265. What is the condition of the molecules of bodies? 266. Illustrate conduction. 267. Show that different substances have different conducting powers. 268. Show that liquids and gases are poor conductors of heat. 269. Show that a body in cooling 1° gives out as much heat as it takes to warm it 1°. 270. Show that it takes different amounts of heat to raise the temperature of the same weight of different substances 1°. 271. Define a unit of heat. 272. Define specific heat. 273. Find the specific heat of bodies by the method of mixture. 274. By the method of fusion. 275. Find the specific heat of liquids and gases by means of the calorimeter. 276. Show that heat will melt a solid. 277. What is meant by the melting-point? 278. Show that liquids have latent heat. 279. Find the latent heat of a liquid. 280. Explain the boiling of liquids. 281. Show that gases have latent heat. 282. Upon what does the state of a body depend? 283. Show the effect of pressure upon the boiling-point. 284. Of cohesion. 285. Of the nature of the vessel. 286. Describe and explain the spheroidal state. 287. Illustrate evaporation. 288. Give an account of the condensation of gases. 289. Describe and explain freezing-mixtures. 290. Show that solids are expanded by heat. 291. That different solids are expanded differently by the same heat. 292. That liquids are expanded by heat. 293. That different liquids are expanded differently by the same heat. 294. That gases are expanded by heat. 295. That all gases are expanded equally by the same heat. 296. Find the coefficient of expansion for mercury. 297. For any liquid. 298. For any solid. 299. For air and other gases. 300. Show that when a gas is not allowed to expand, its elasticity is increased by heat. 301. Illustrate the convection of heat in liquids. 302. How are oceanic currents produced? 303. In gases. 304. Show the effect of the specific and latent heat of water upon climate. 305. Show the effect of its irregular expansion and contraction. 306. What is true of the latent heat of steam and vapor? 307. Explain heating by steam. 308. Describe the mercurial thermometer. 309. Show how it is made. 310. When and why is an alcohol thermometer used? 311. Describe the air thermometer. 312. The differential thermometer. 313. Breguet's thermometer. 314. Show the effect of temperature upon time-pieces. 315. Explain Graham's pendulum. 316. The compensation balance-wheel. 317. Mention other effects of expansion by heat. 318. Explain the dew-point hygrometer. 319. The wet and dry bulb hygrometer. 320. The hygrodeik.

ELECTRICITY.

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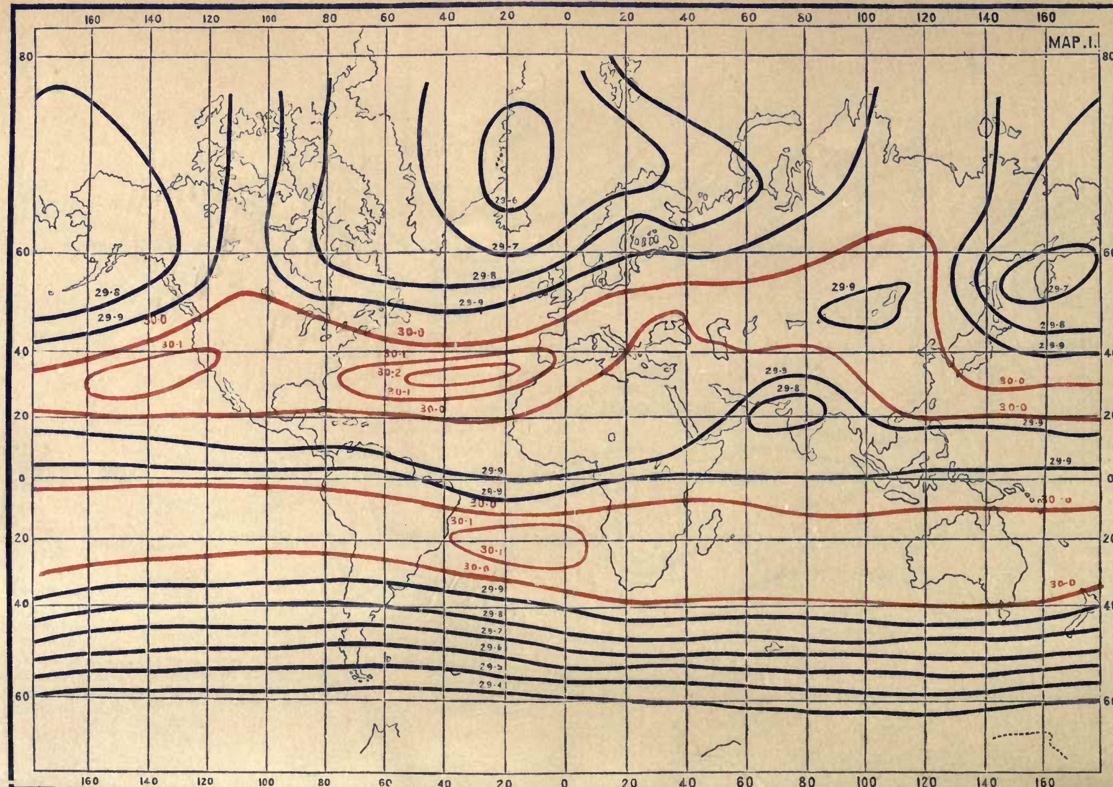

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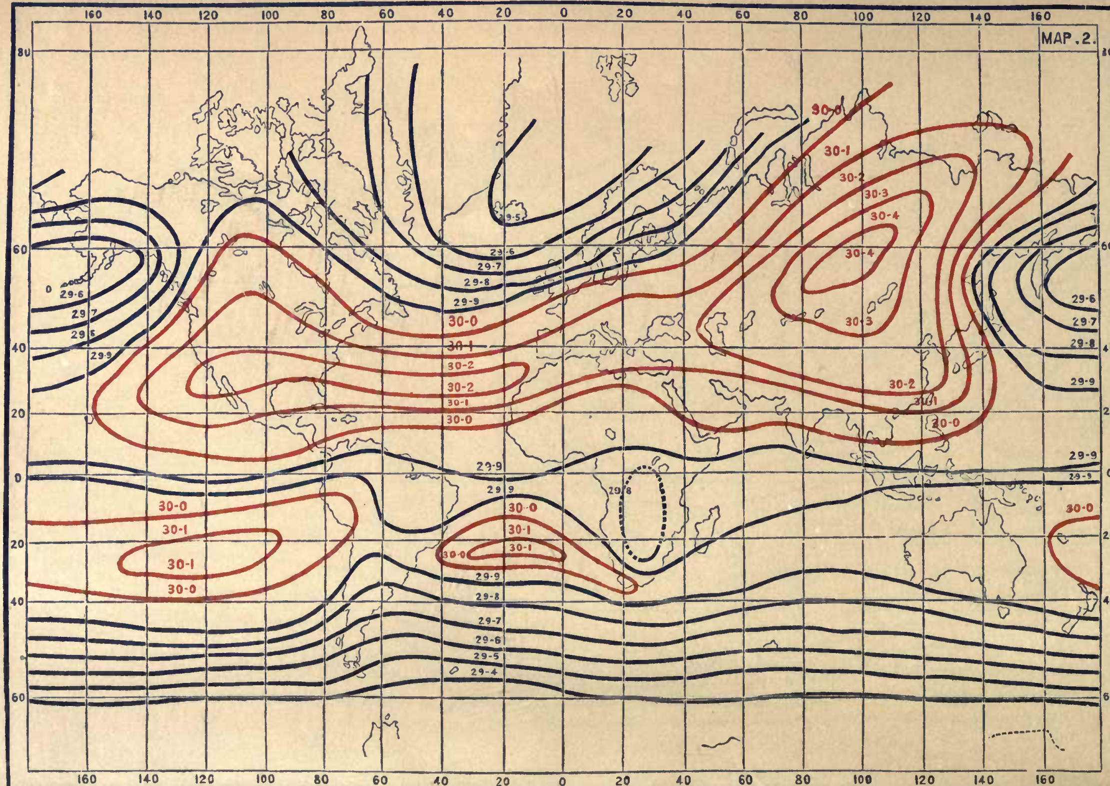
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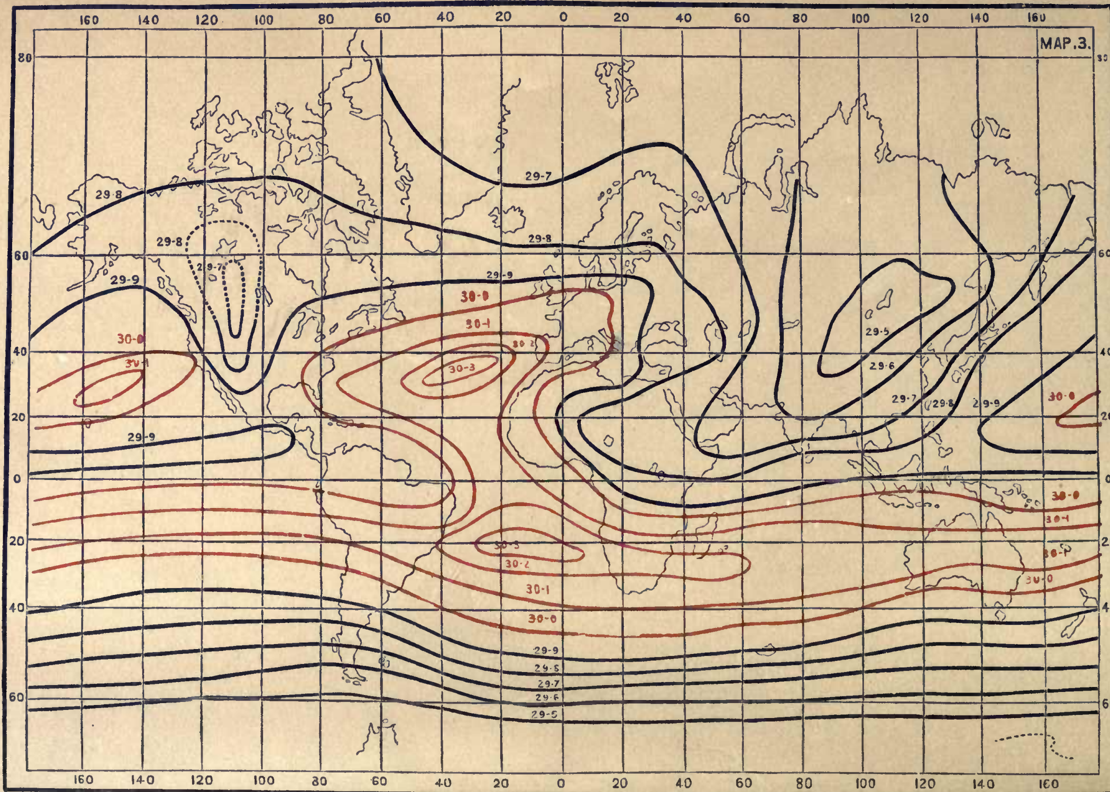
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